

Week 2

# MODIS Snow Covered Area and Grain Size (MODSCAG)

Thomas H. Painter  
Chris Mattmann  
(NASA JPL)

**ARSET**

**A**ppplied **R**emote **SE**nsing **T**raining

A project of NASA Applied Sciences

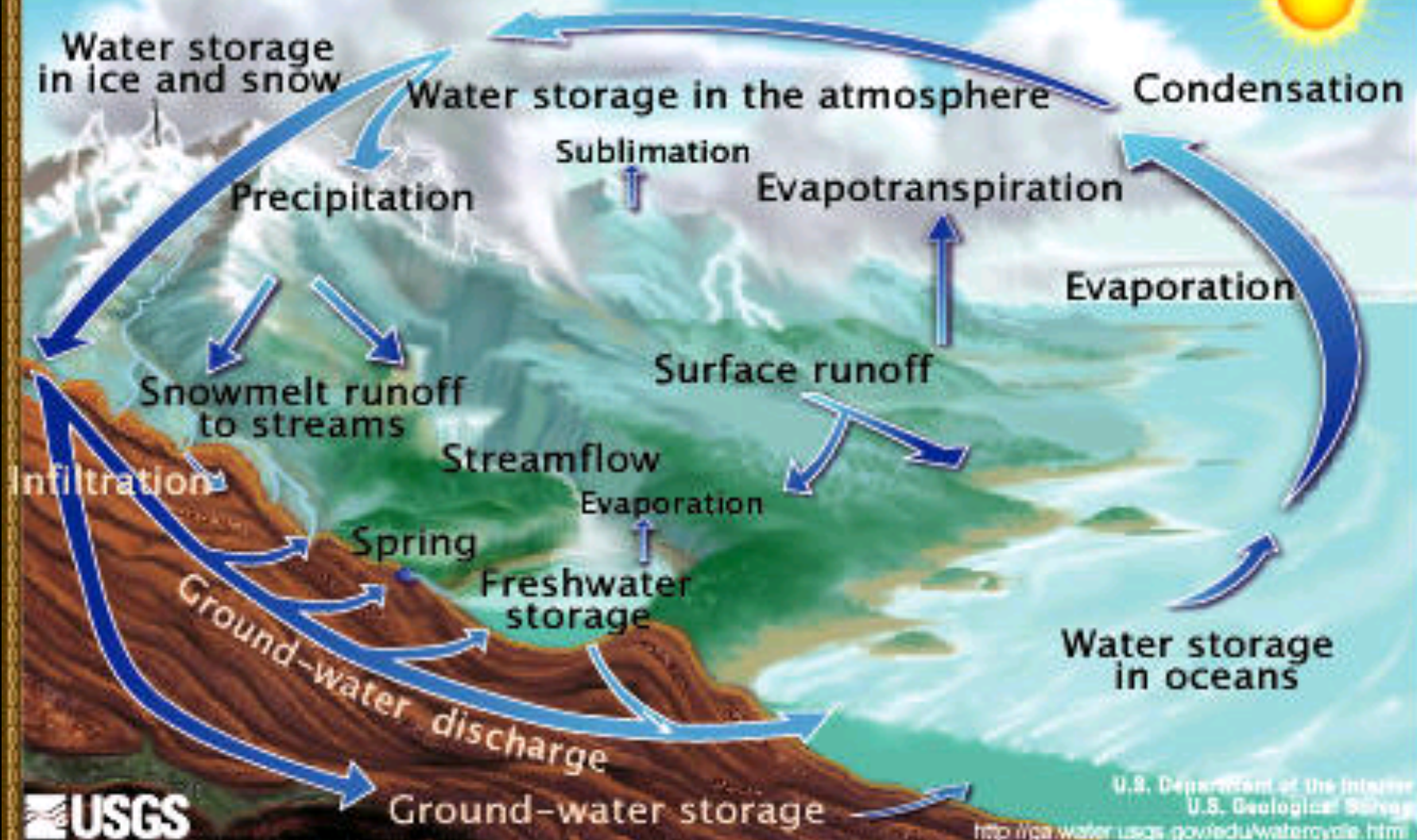


# Outline

- NASA water science
- Direct products:
  - Fractional Snow Covered Area
  - Grain Size
  - applications
- Derived products:
  - Snow Water Equivalent Reconstruction
  - Ice products
  - applications



# The Water Cycle



# NASA in Water Science?!



Caltech students (1936)



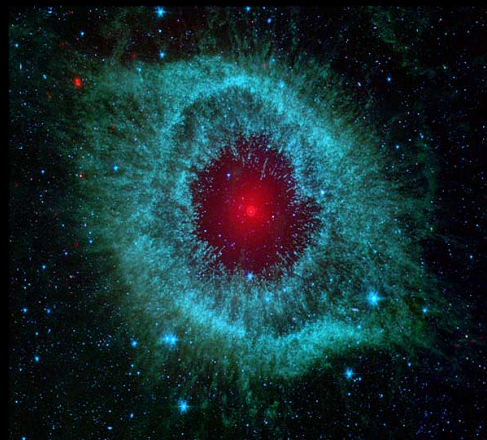
Missiles (1940s)



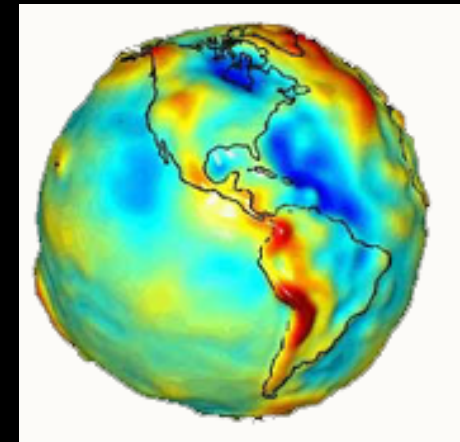
Explorer 1 (1958)



Mars Exploration Rovers (2004  
– present)



Spitzer Space Telescope (2004 –  
present)



Earth Science (1978  
– now)

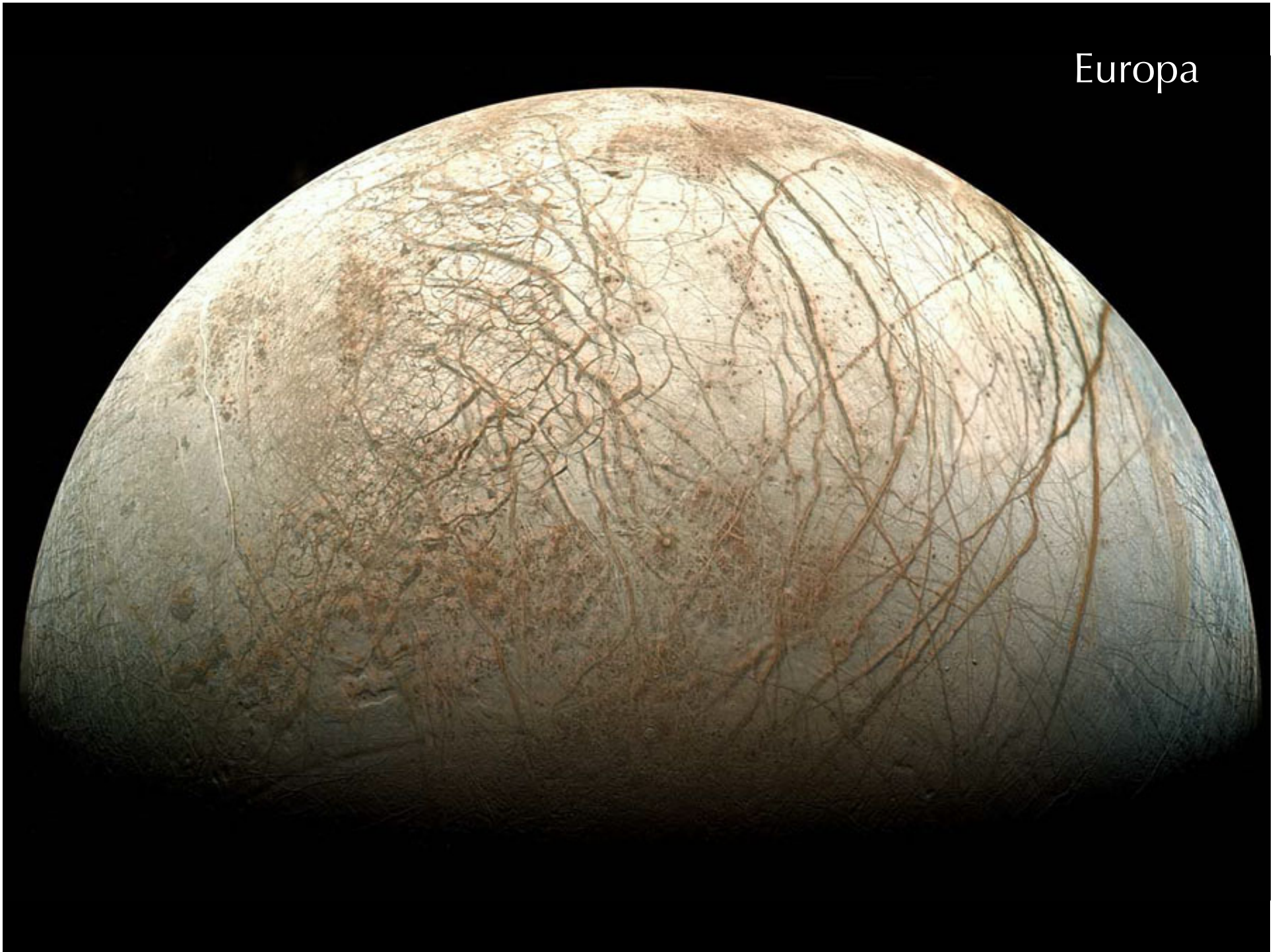


Mars



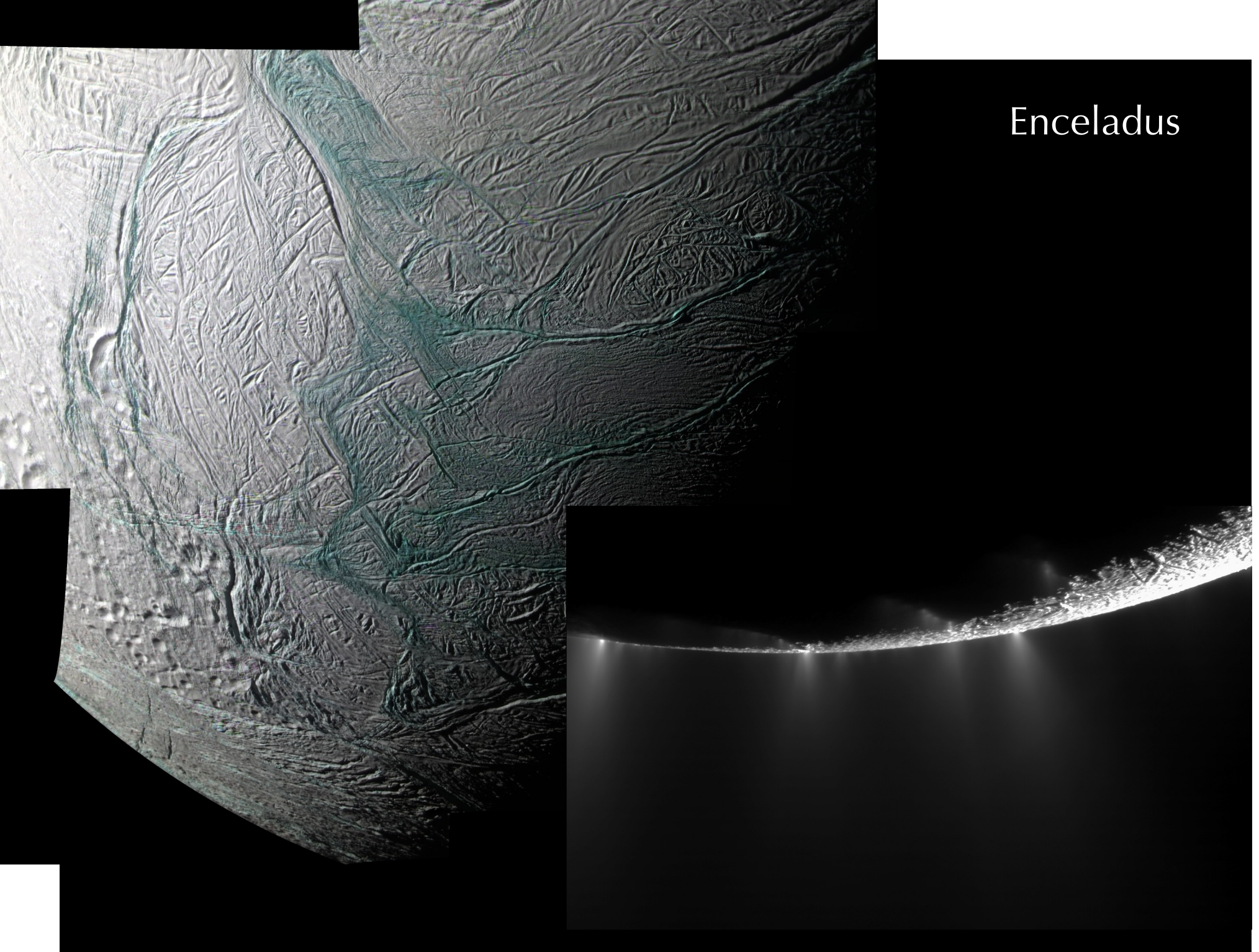


Europa





# Enceladus





Earth









# Summary: NASA Remote Sensing and Model-derived Water Resource Quantities

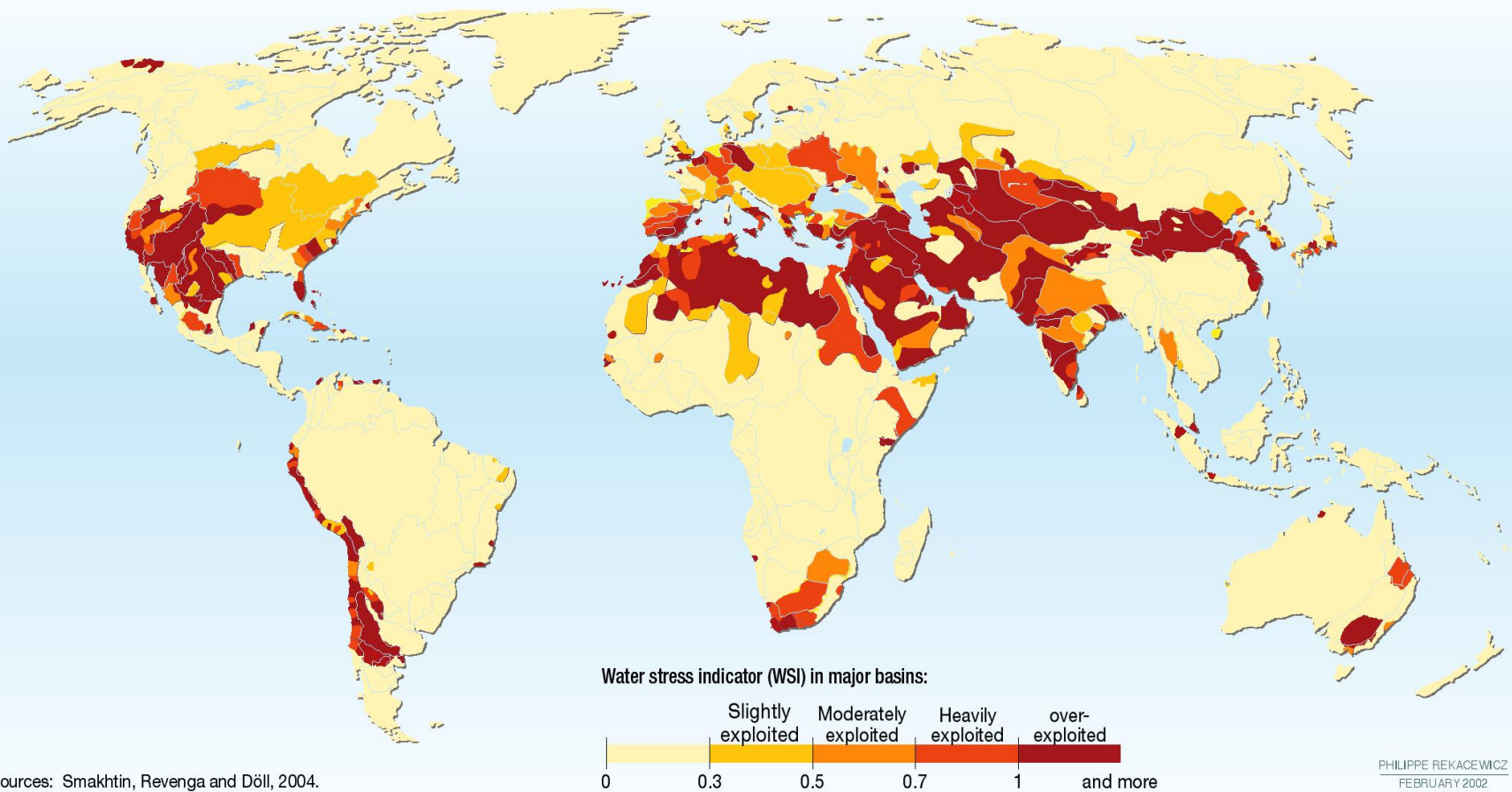
• Rain:	Units
Rain Rate at surface (amount of rainfall per unit area per unit of time)	mm/hour
Accumulated Rain (rain amount over a day or a month)	mm
Vertical Precipitation Rate profile (liquid and frozen rain rate at various levels in the atmosphere)	mm/hour
• Snow:	
Snowfall Rate (amount of snowfall per unit area per unit of time)	Kg/m <sup>2</sup> /hour
Fractional Snow Cover Area	Fraction
Snow Depth	m
Snow Mass	Kg/m <sup>2</sup>
Snow water Equivalent	Kg/m <sup>2</sup>
Snow Albedo	Unitless
• Soil Moisture:	
Top Soil Layer Wetness	Fraction
Soil Moisture	Kg/m <sup>2</sup>
• Ground Water:	
Column Equivalent of Water	cm
[ground water+soil moisture +surface water]	
• Evapotranspiration:	Kg/m <sup>2</sup>
• Total Storage	m



# Need for Snow Measurements

- *Why are snow covered area and grain size important for water resources management ?*
  - Knowledge of starting and remaining coverage
  - Knowledge of reduction in snow cover
  - Remote sensing covers areas that snow pillows and snow courses do not – therefore, more complete knowledge through snowmelt
  - Grain size -> albedo – rate of snowmelt

# Global water stress



# Snow Dominated Regions

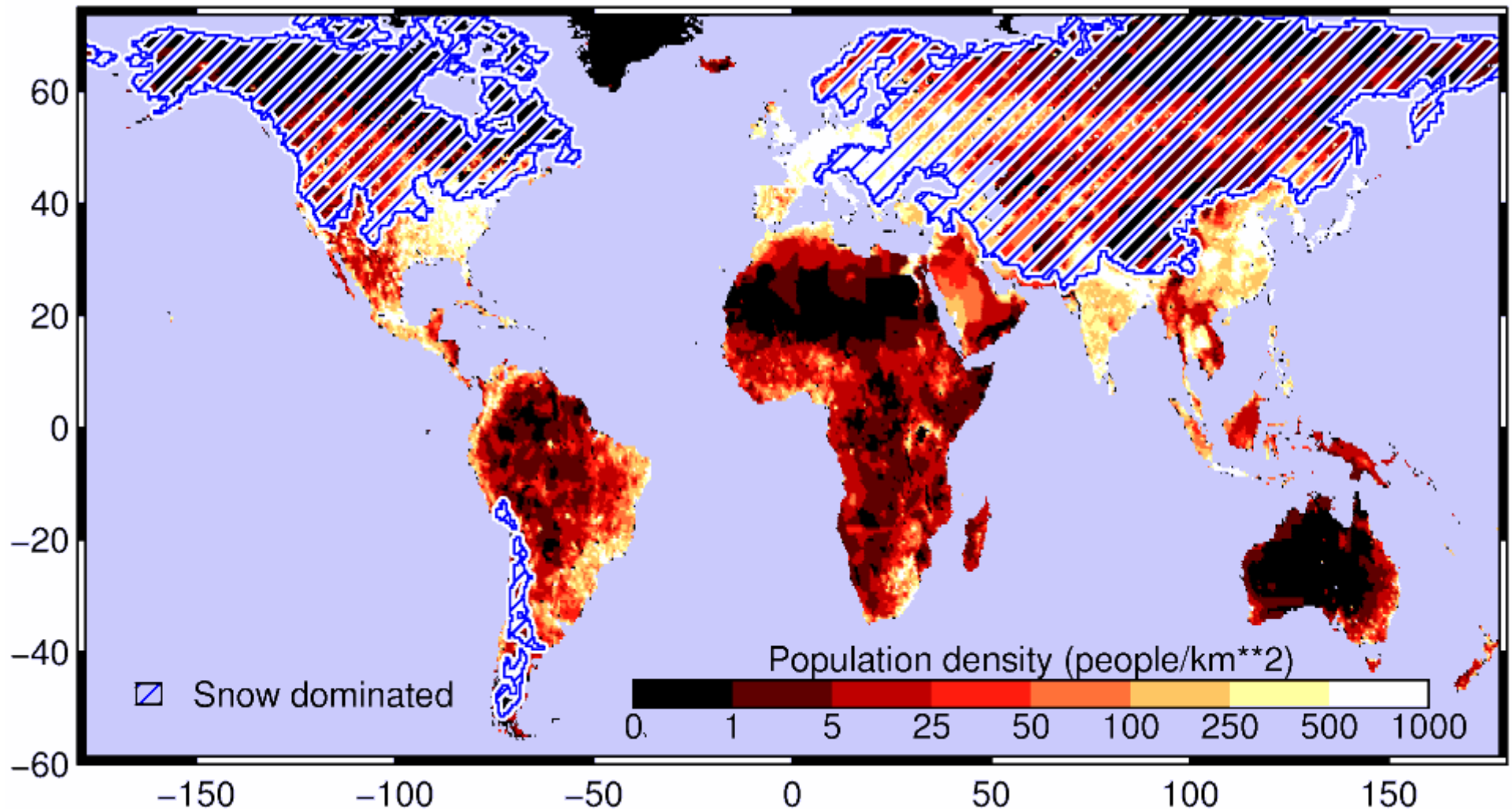
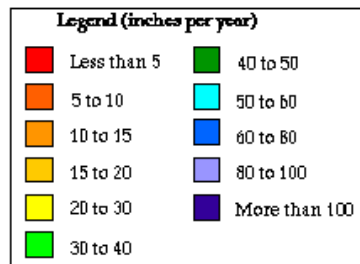
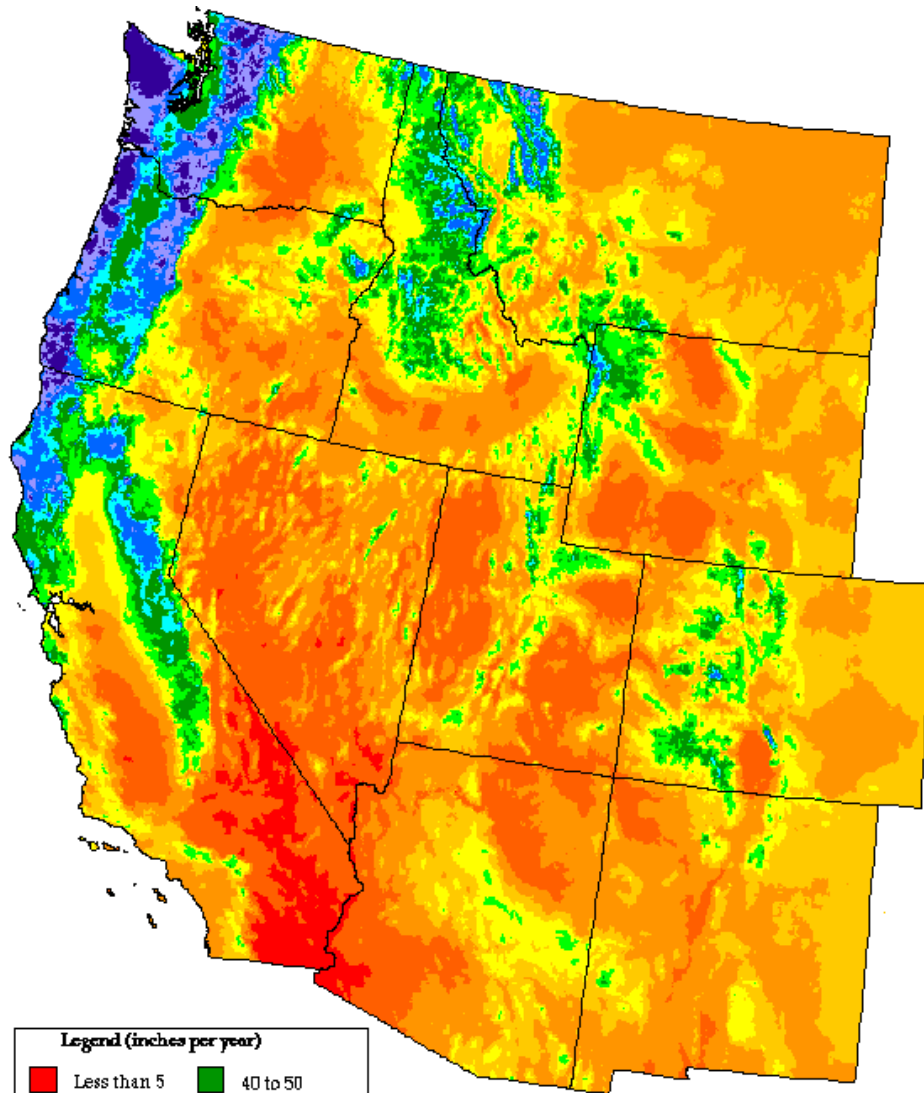


Figure courtesy Tim Barnett (Scripps Inst. Ocean)



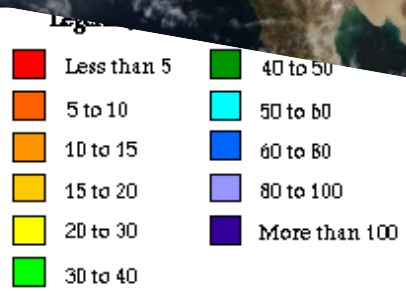
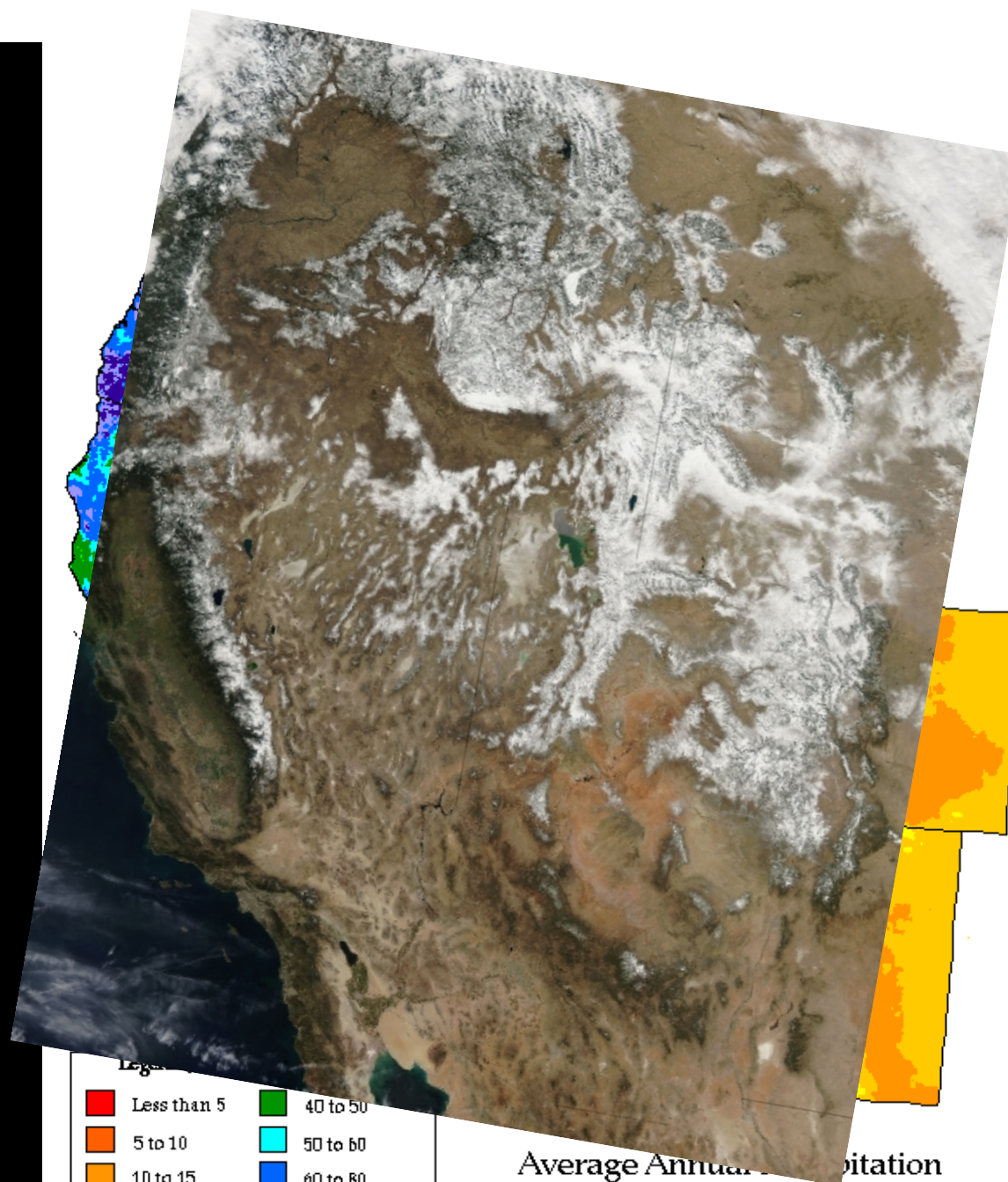
### Average Annual Precipitation

Western United States

Period: 1961-1990 Units: inches







## Average Annual Precipitation

Western United States

Period: 1961-1990 Units: inches



# LOS ANGELES

CENT ANNE

ADDRESS  
YOUR MAIL  
TO



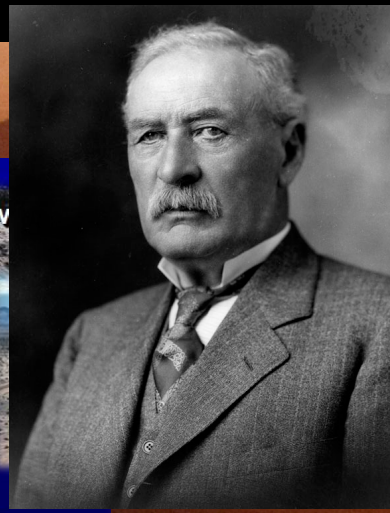
## CALIFORNIA

Mr David Wright  
3272 - W. 6th Ave.  
Vancouver B.C.  
Canada

© C. T. & Co.



# Southern California Water



William Mulholland

Frank Weymouth



Gov. Pat Brown



The

LOS ANGELES

Times

XXXII<sup>ND</sup> YEAR.

THURSDAY, NOVEMBER 6, 1913.—EDITORIAL SECTION.

POPULATION { By the Federal Census (1910)—318,3  
By the City Directory (1913)—483,4

## GLORIOUS MOUNTAIN RIVER NOW FLOWS TO LOS ANGELES' GATES

Inquiry.

LOS ANGELES INVESTMENT  
L. COMPANY INVESTIGATED.*Federal Authorities Act Under Orders  
from Washington Chiefs.**Complaints that Misleading Statements Have Been  
Sent Through the Mails by Officials of Elder's Com-  
panies to Cause Scrutiny of Books and Possible Or-  
ganization—Stockholders to Be Protected.*

FOLLOWING a secret investigation by the Federal authorities of complaints to the effect that officers of the Los Angeles Investment Company have sent misleading statements of the financial condition of the concern through the United States mails, it is believed the affairs of the company will be brought to a crisis today. The investigation was ordered by United States Attorney-General McReynolds and Postmaster-General Burleson.

The plans of the government officials are twofold. One is to co-operate in every way with leading financiers of the city who, it is declared, wish to reorganize the investment company and safeguard the stockholders. The other is to examine books, documents, transfers and instruments of every description to ascertain whether fraud has been practiced by any of the officers of the company.

It was admitted by the Federal authorities yesterday that C. A. Elder, president and general manager of the company, is under fire. He has been generally held responsible for the remarkable rise of the Los Angeles In-

vestment company, because it was generally held responsible for the remarkable rise of the Los Angeles In-

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A scenic landscape photograph of a snow-capped mountain range reflected in a calm lake. The mountains are rugged and covered in patches of snow, with a clear blue sky above. The foreground shows a dense forest of evergreen trees on the slopes leading down to the water. The text "Colorado River Basin" is overlaid in white, serif font across the lower portion of the image.

# Colorado River Basin



John Wesley Powell



Glen Canyon, Hillers, 1871  
Powell Expedition



# Lake Powell



# Lake Mead and the Shortage



Sen. Johnson



# COLORADO RIVER COMPACT

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SIGNED AT

SANTA FE, NEW MEXICO

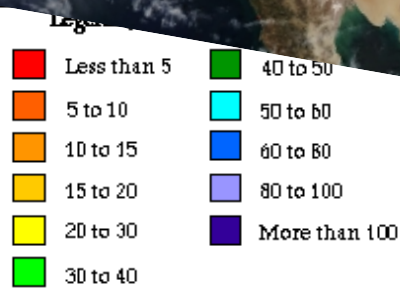
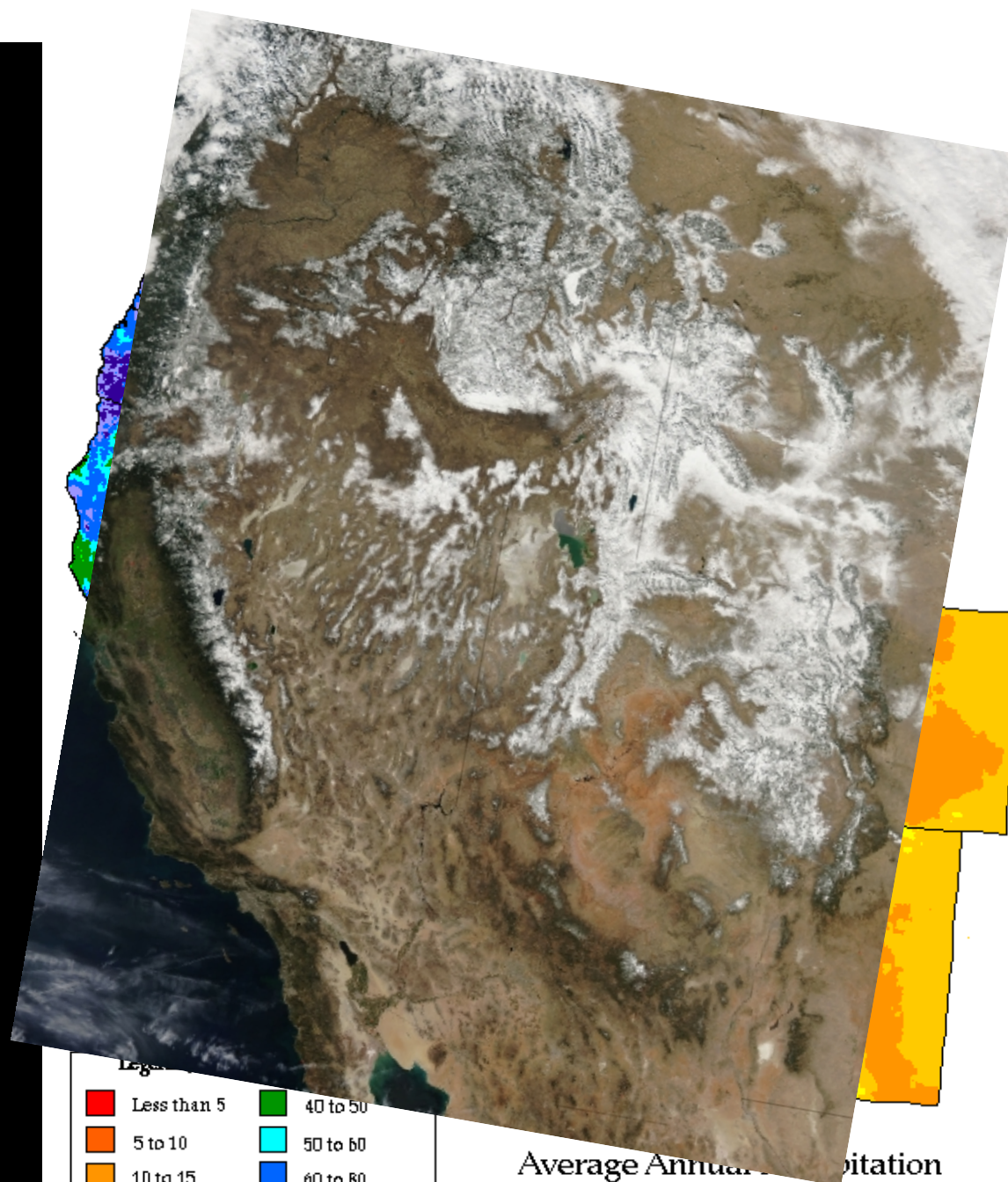
NOVEMBER 24, 1922

## ARTICLE III

(a) There is hereby apportioned from the Colorado River System in perpetuity to the Upper Basin and to the Lower Basin, respectively, the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum, which shall include all water necessary for the supply of any rights which may now exist.

(b) In addition to the apportionment in paragraph (a), the Lower Basin is hereby given the right to increase its beneficial consumptive use of such waters by one million acre-feet per annum.

(c) If, as a matter of international comity, the United States of America shall hereafter recognize in the United States of Mexico any right to the use of any waters of the Colorado River System, such waters shall be supplied first from the waters which are surplus over and above the aggregate of the quantities specified in paragraphs (a) and (b); and if such surplus shall prove insufficient for this purpose, then, the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin, and whenever necessary the States of the Upper Division shall deliver at Lee Ferry water to supply one-half of the deficiency so recognized in addition to that provided in paragraph (d).



## Average Annual Precipitation

Western United States

Period: 1961-1990 Units: inches

# Satellites providing Snow Products

Satellite	Sensors	Quantities
Terra	MODerate Resolution Imaging Spectroradiometer (MODIS)  500 m spatial resolution ~daily temporal resolution	<ul style="list-style-type: none"> <li>• Snow covered area</li> <li>• Snow albedo</li> <li>• Snow grain size</li> <li>• Dust/BC radiative forcing</li> </ul>
Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)  500 m spatial resolution ~daily temporal resolution	<ul style="list-style-type: none"> <li>• Snow covered area</li> <li>• Snow albedo</li> <li>• Snow grain size</li> <li>• Dust/BC radiative forcing</li> </ul>
NPOESS Preparatory Project (NPP) - Suomi	Visible Infrared Imaging Radiometer Suite (VIIRS)  750m spatial resolution ~daily temporal resolution	<ul style="list-style-type: none"> <li>• Snow covered area</li> <li>• Snow albedo</li> <li>• Snow grain size</li> <li>• Dust/BC radiative forcing</li> </ul>
Landsat Data Continuity Mission (LDCM) (launch February 2013)	Operational Land Imager (OLI)  30 m spatial resolution 16-day temporal resolution	<ul style="list-style-type: none"> <li>• Snow covered area</li> <li>• Snow albedo</li> <li>• Snow grain size</li> <li>• Dust/BC radiative forcing</li> </ul>



# Parameter Definitions

*snow water equivalent*

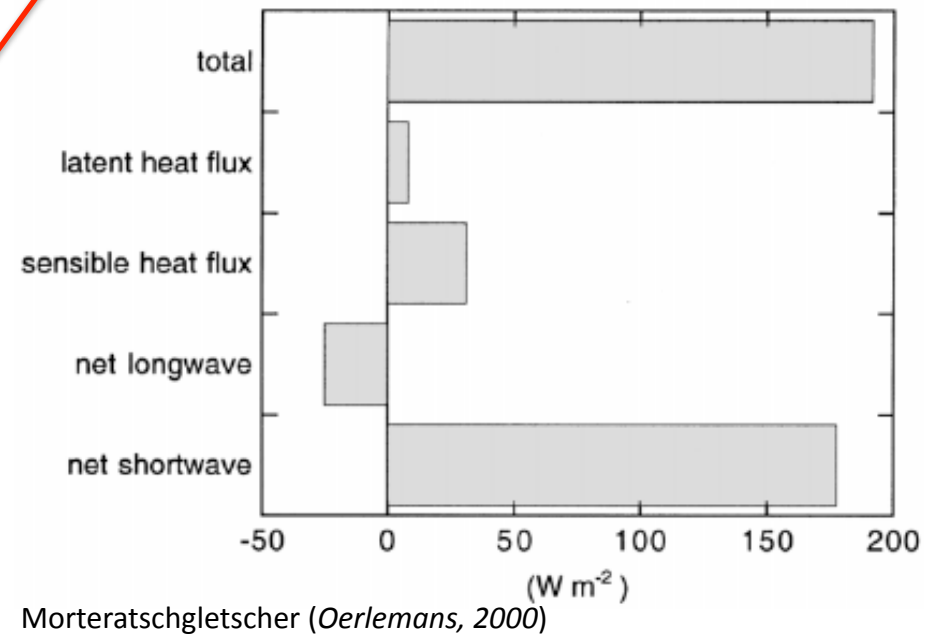
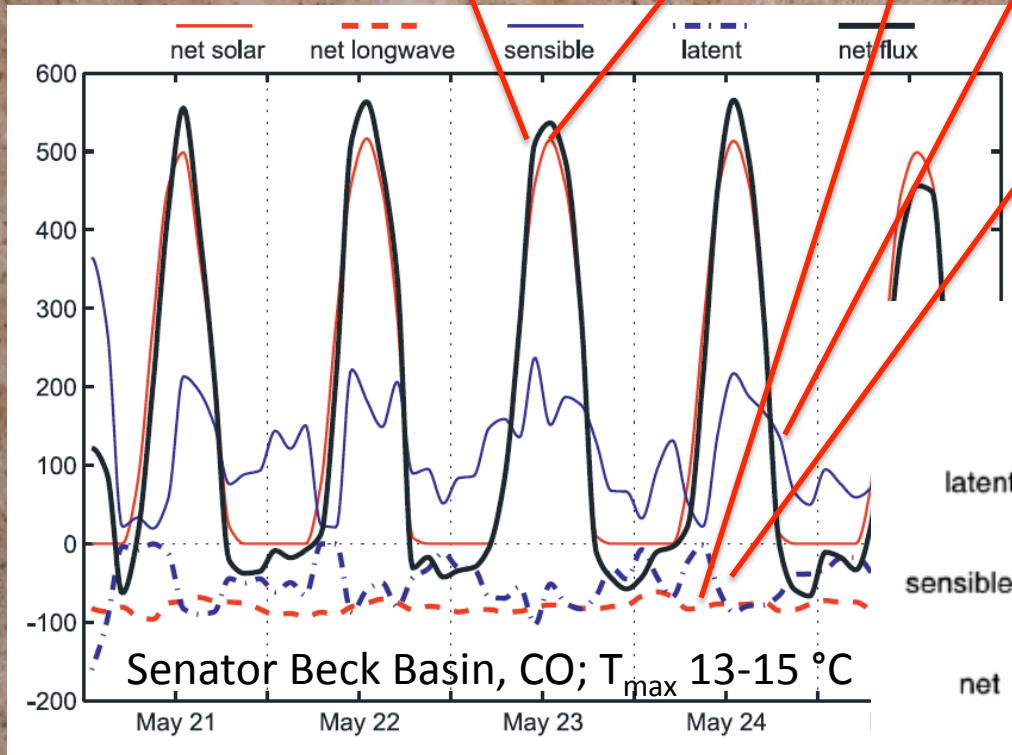
the depth of water to which a snowpack melts down

*snow albedo*

total reflectivity of snow to incoming sunlight

$$\frac{dU}{dt} + Q_m = (1 - \alpha)S + L^* + Q_s + Q_v + Q_g + Q_r$$

What controls  
snowmelt?



Elk Range, Colorado River Basin, April 2009

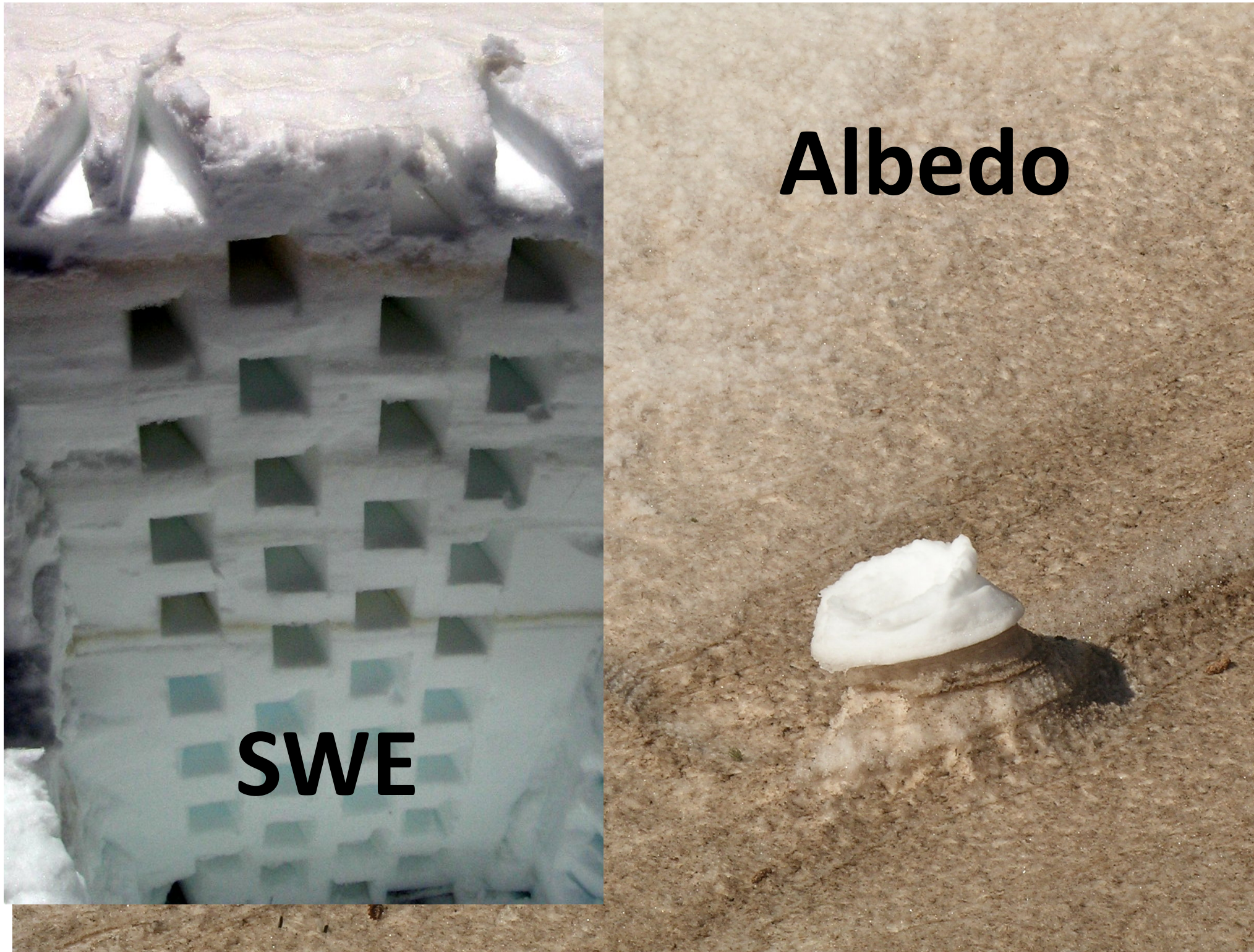






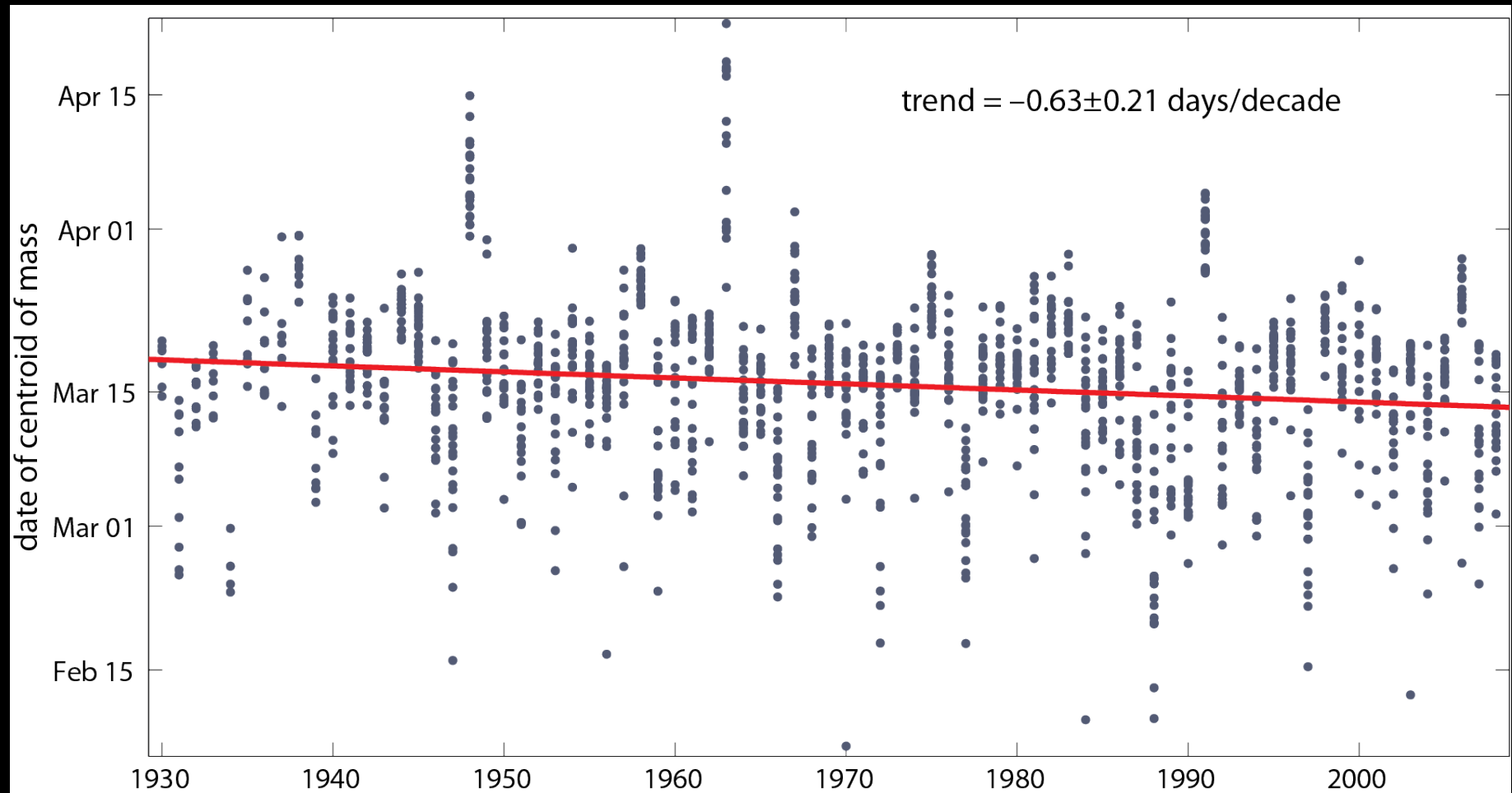


**Albedo**





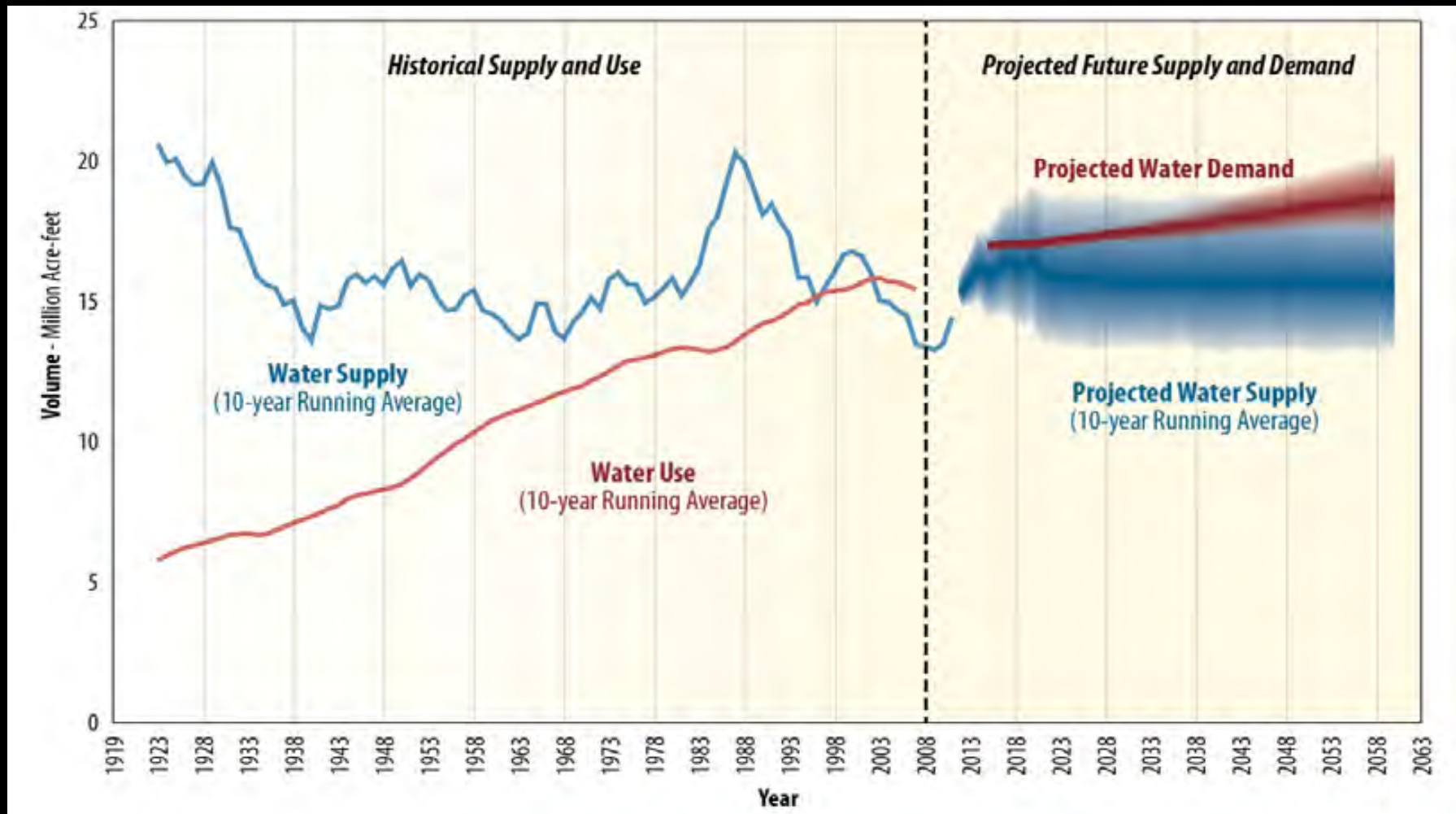
# Sierra Nevada - changes



22 stations with > 75% of 1930-2008 record

[Kapnick & Hall, 2010]

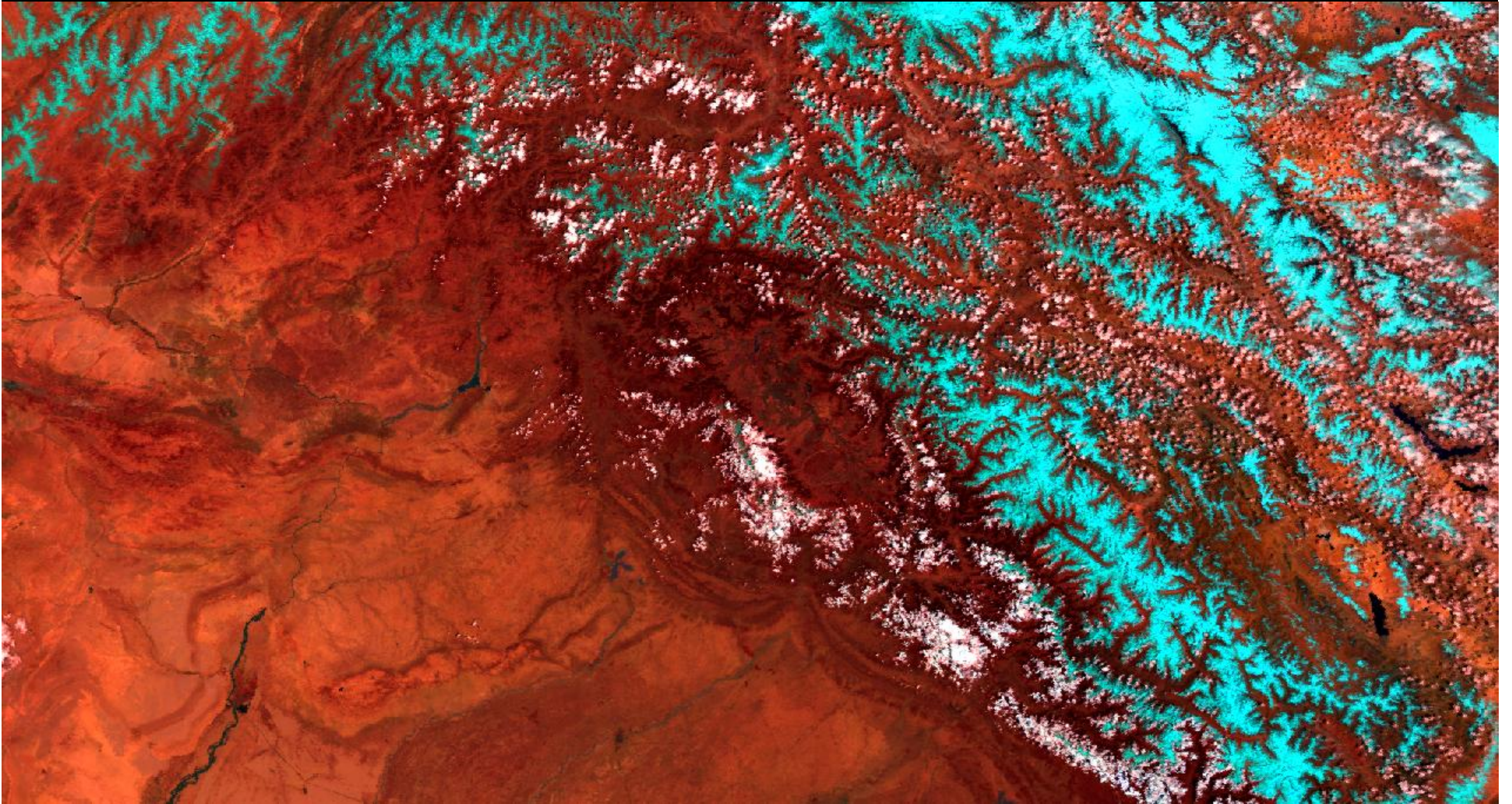
# Colorado River: Historical and Projected Use



**Source:** Colorado River Basin Water Supply and Demand Study, US Department of the Interior Bureau of Reclamation, December 2012,  
<http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html>



# Observations



Hindu Kush - Himalaya

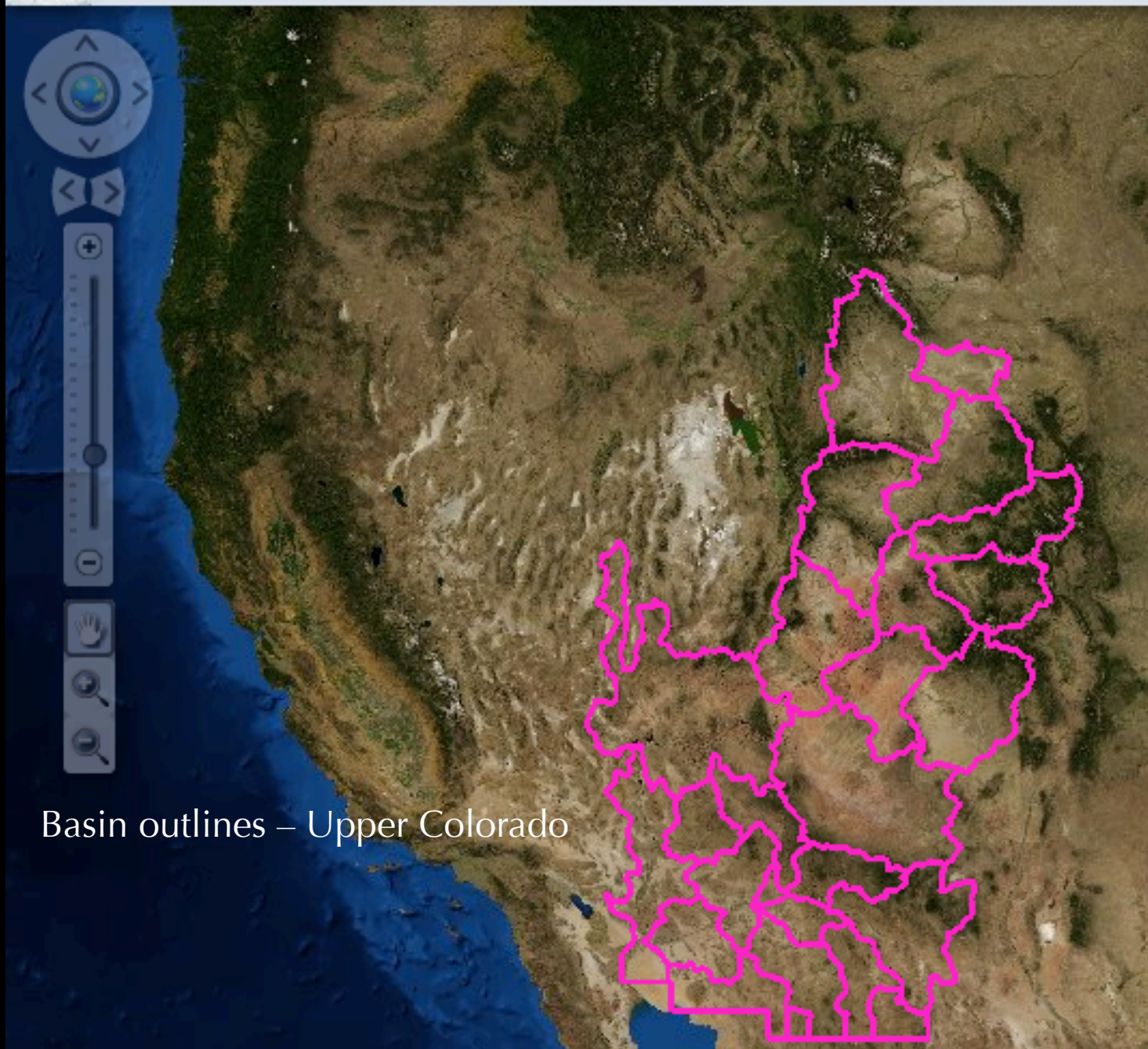




Manual measurement of SWE (snow water equivalent), started in the Sierra Nevada in 1910



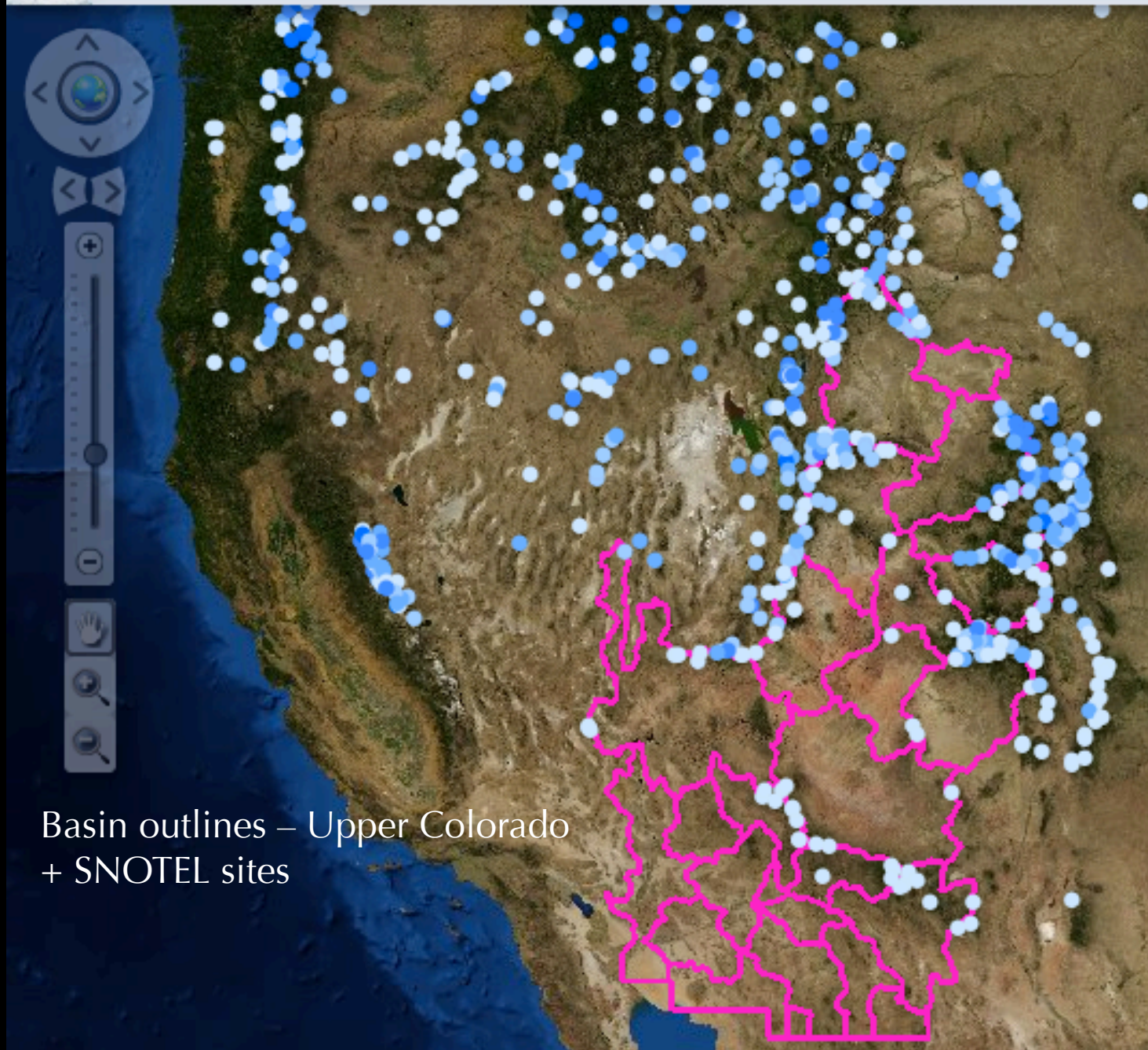




Basin outlines – Upper Colorado



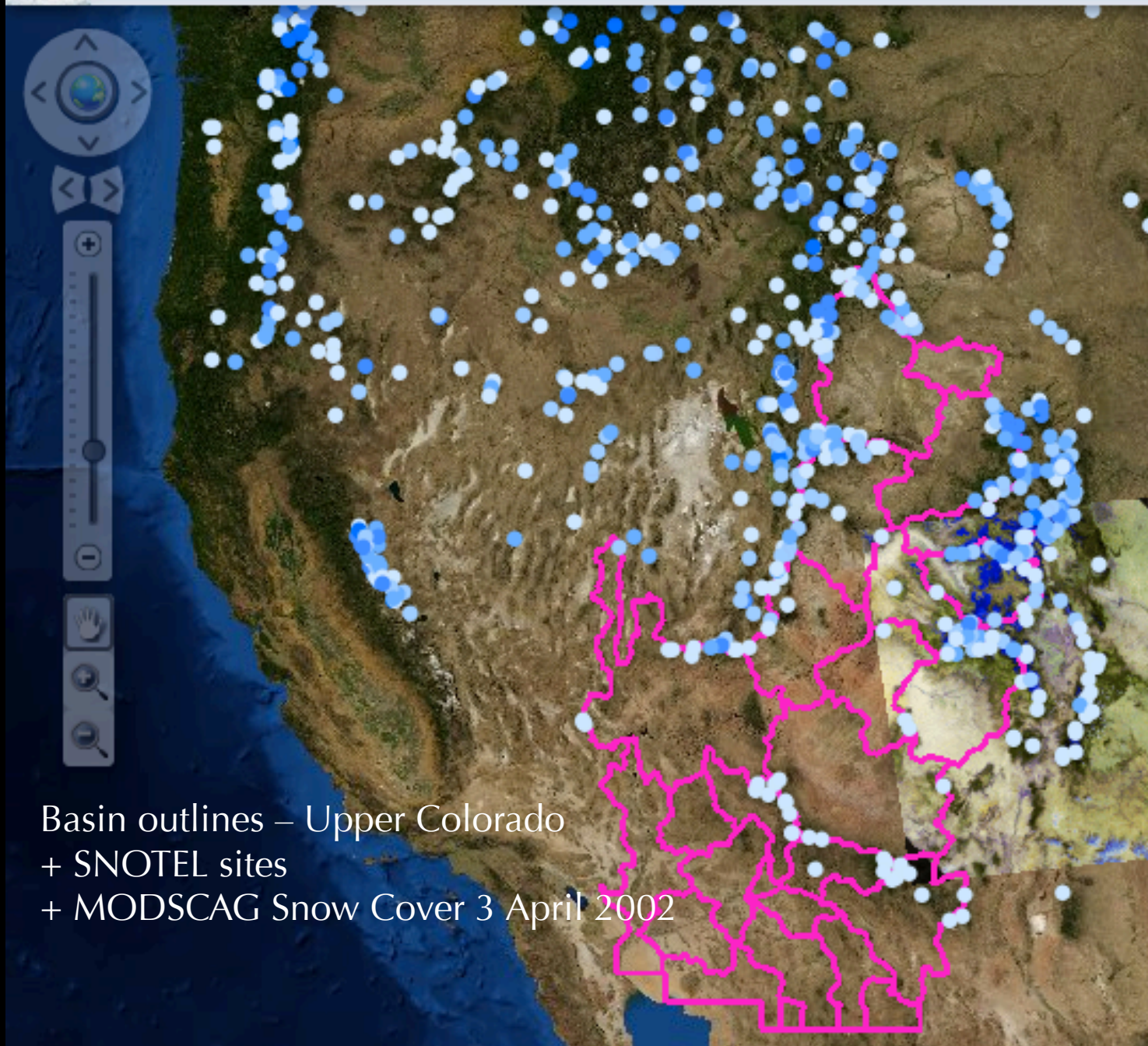
## SNOWMAP alpha



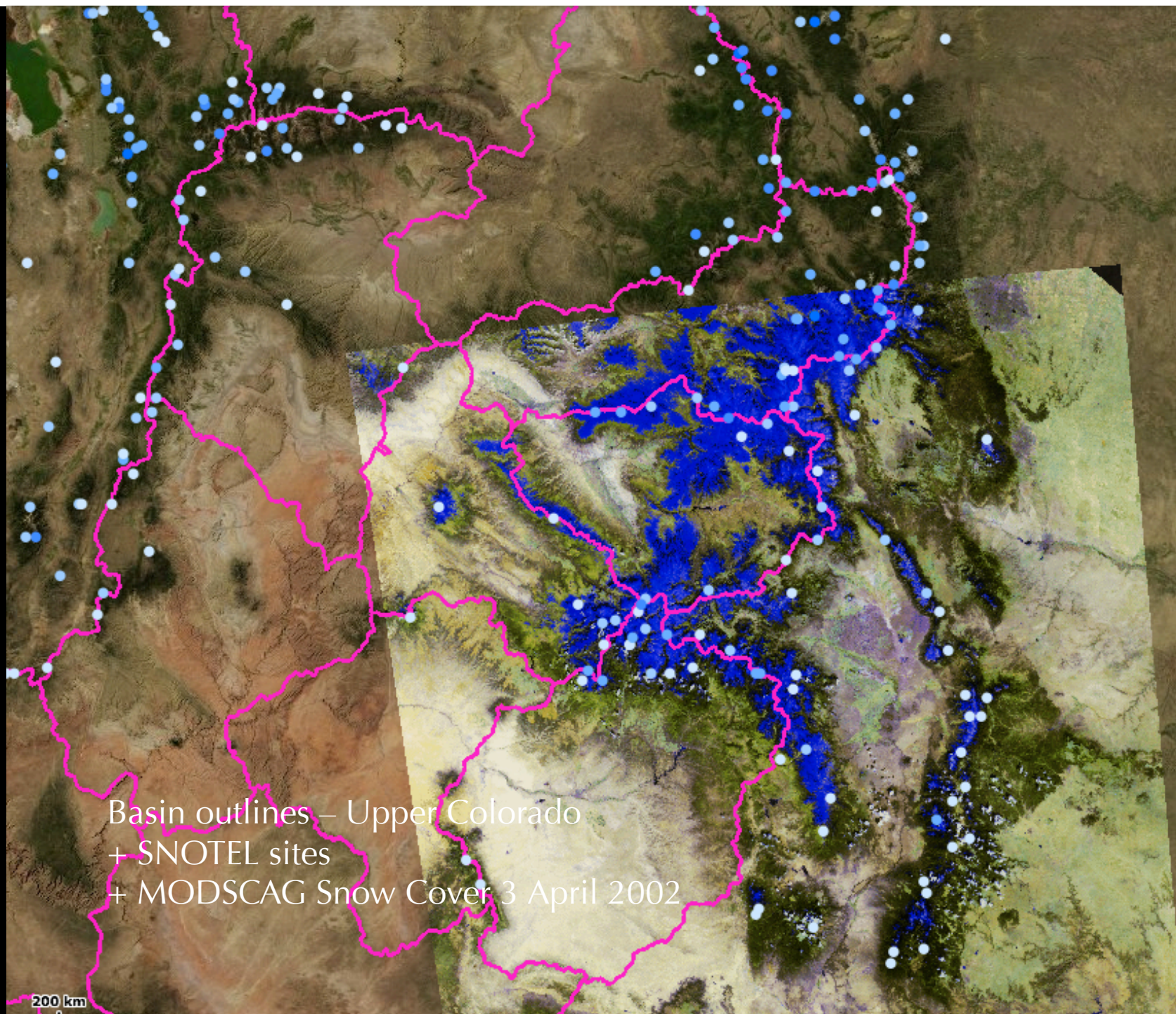
Basin outlines – Upper Colorado  
+ SNOTEL sites



## SNOWMAP alpha



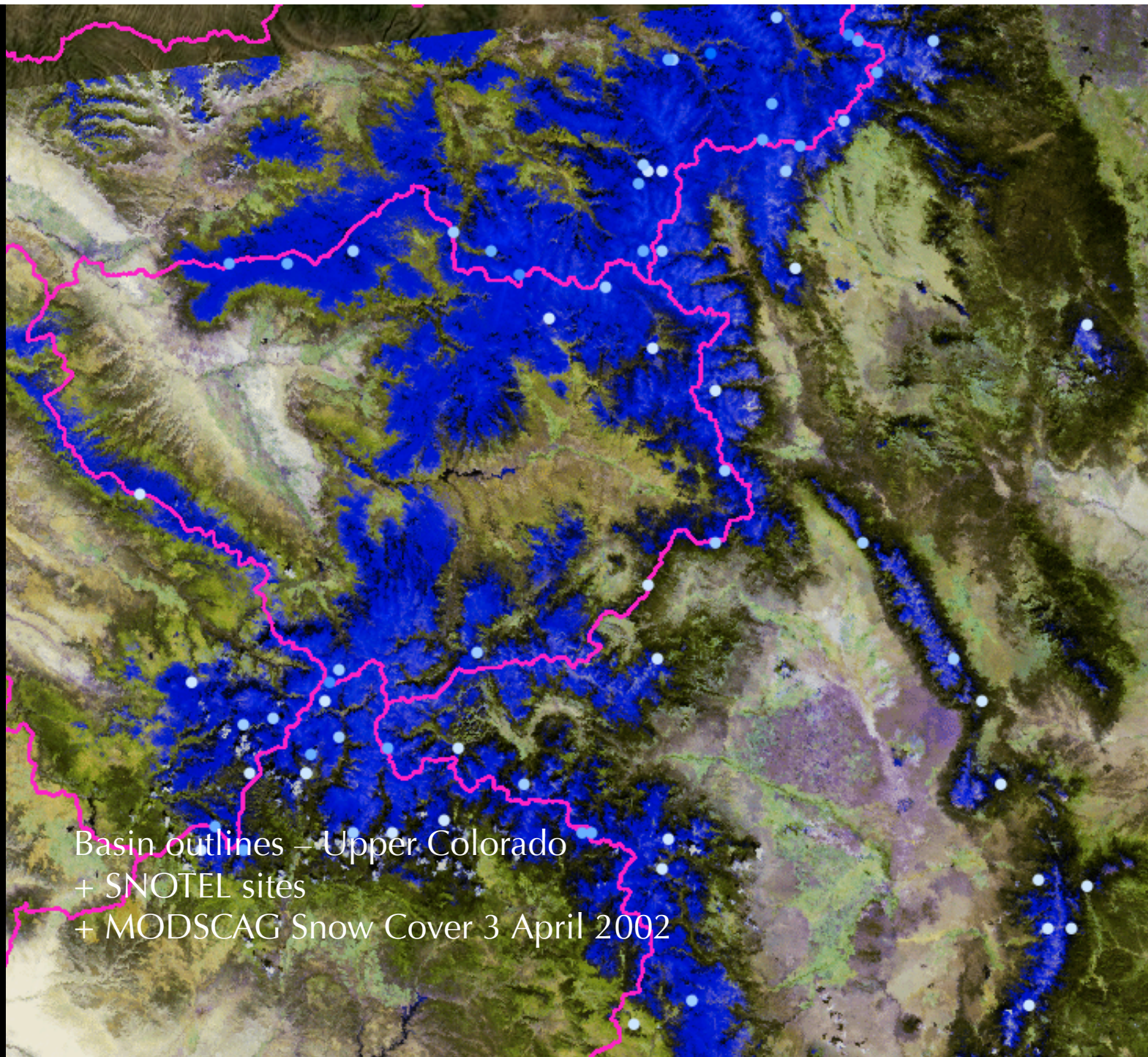




Basin outlines – Upper Colorado  
+ SNOTEL sites  
+ MODSCAG Snow Cover 3 April 2002

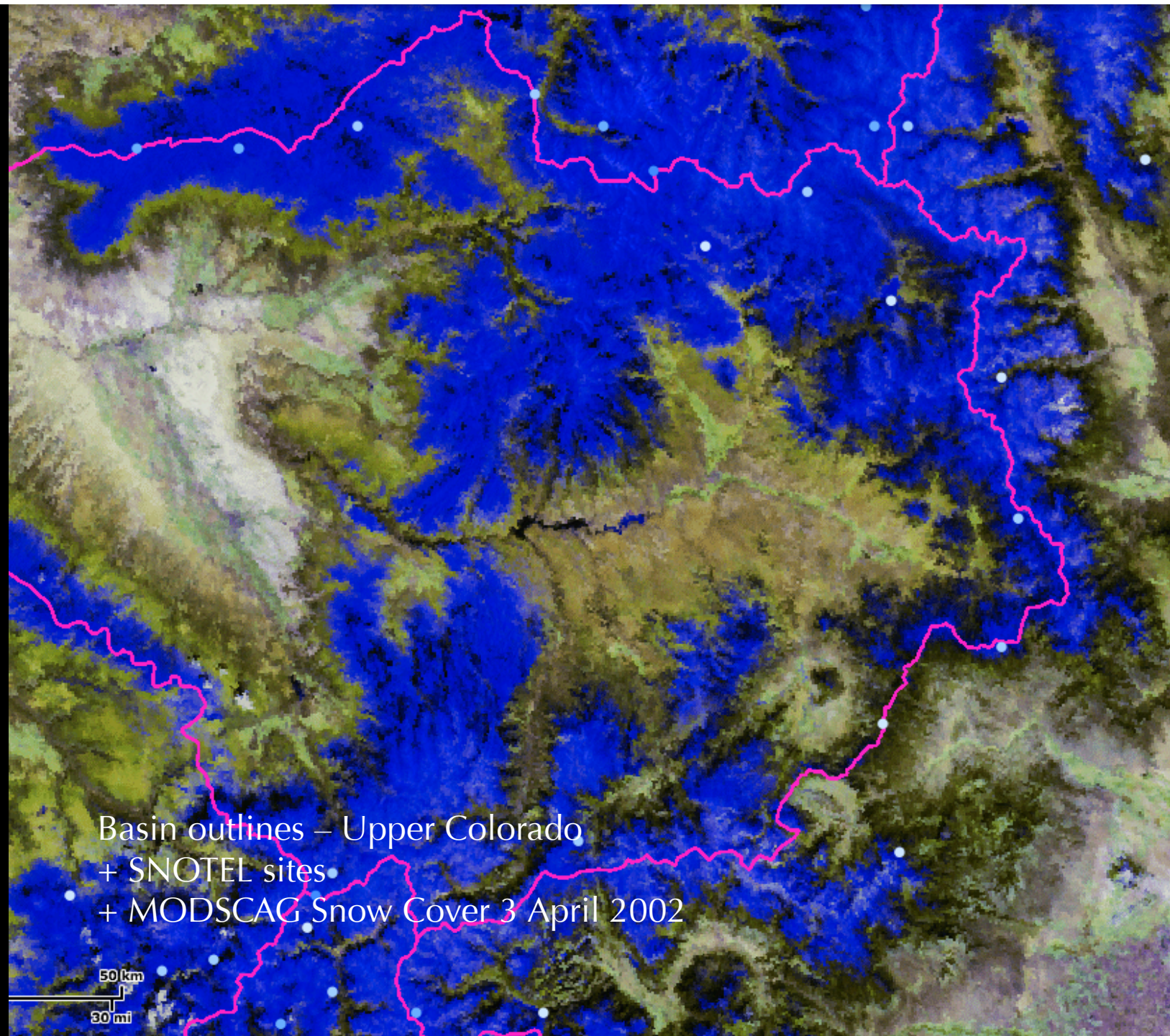
200 km





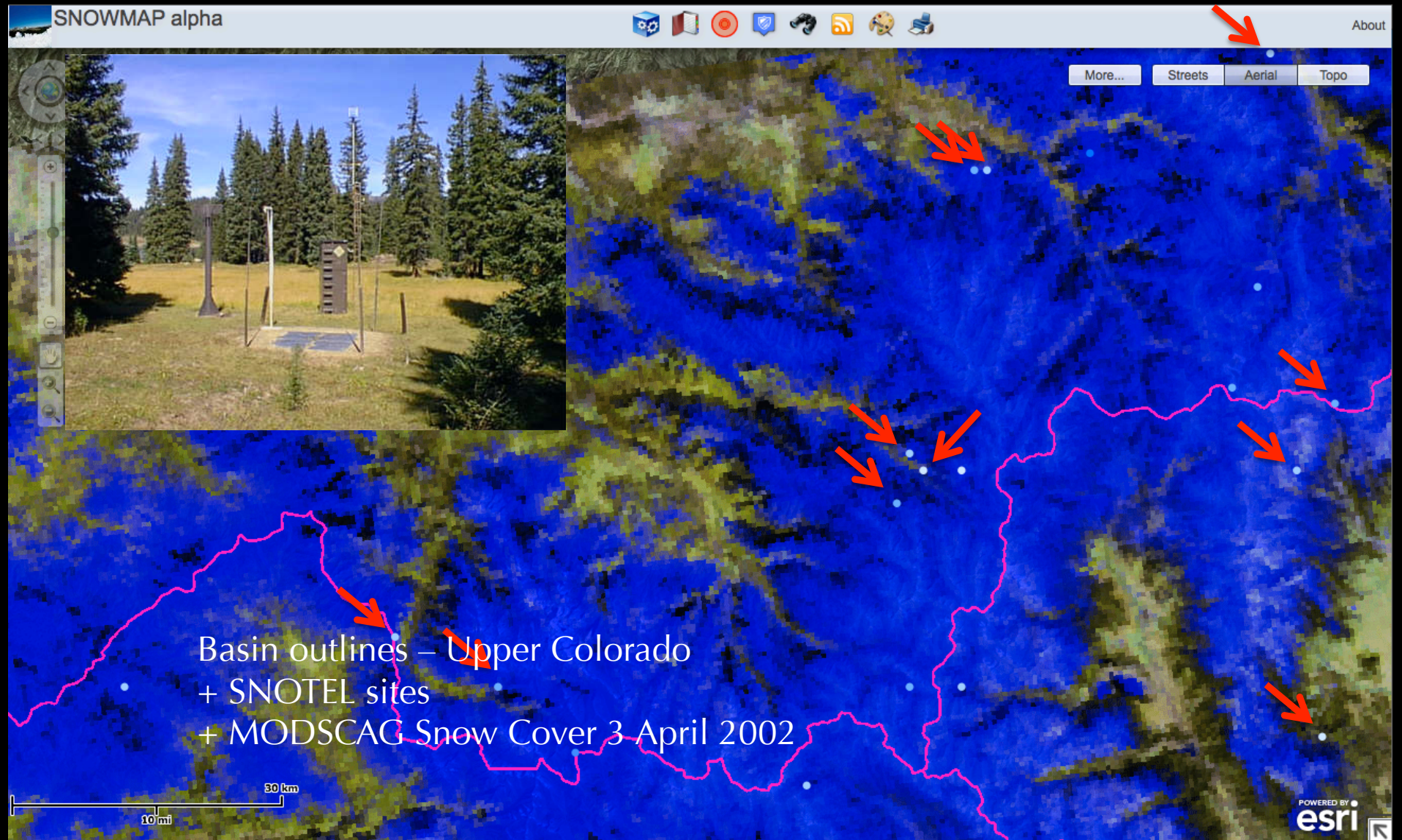
Basin outlines – Upper Colorado  
+ SNOTEL sites  
+ MODSCAG Snow Cover 3 April 2002







# Snow Covered Area



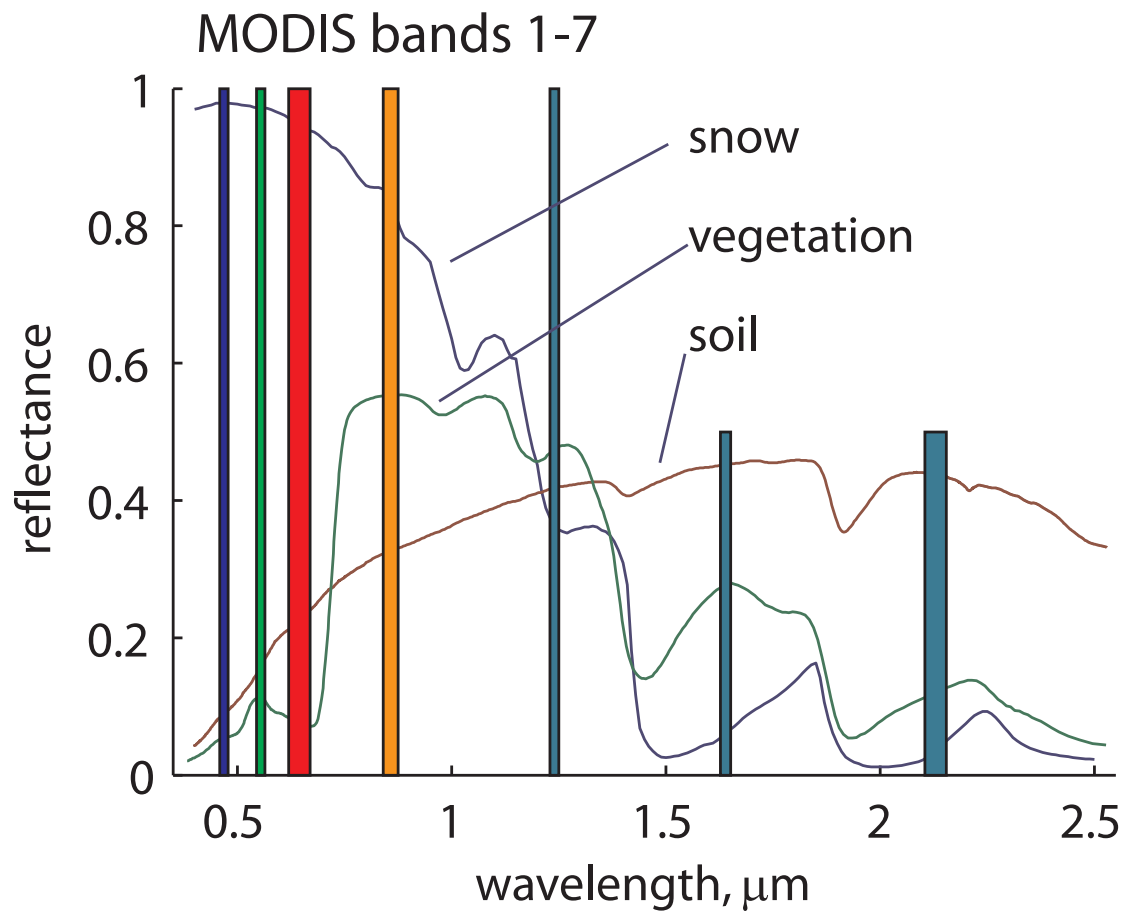
**MODSCAG**



# What is MODSCAG?

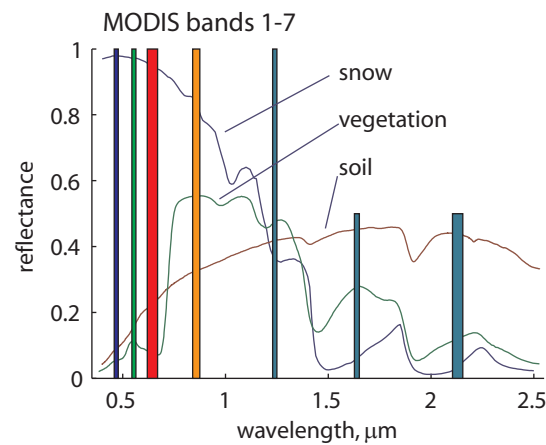
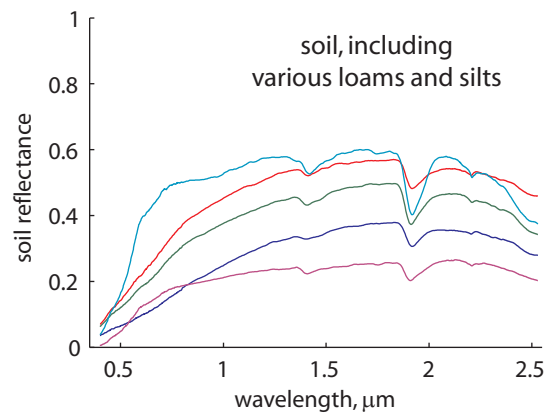
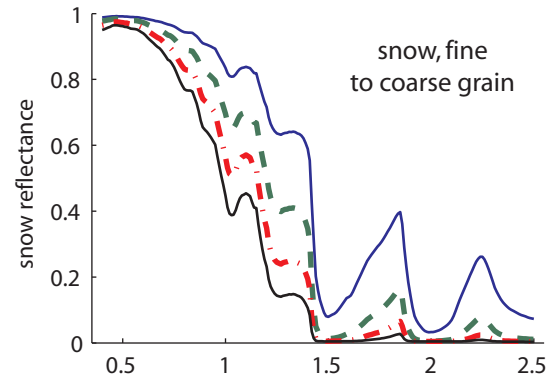
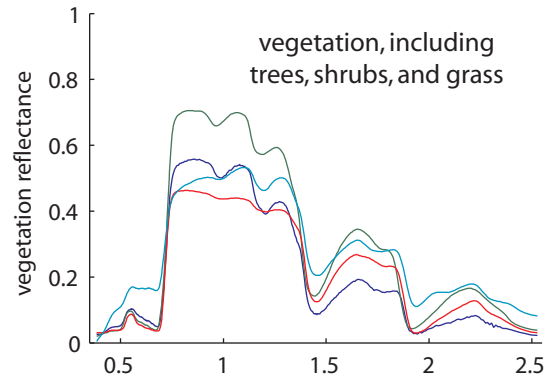
- Uses the MODIS surface reflectance bands
- Matrix inversion to retrieve fraction of snow cover in each pixel
- Also determines the grain size and albedo of that fractional snow cover (giving what modelers want, not the composite)
- Far more accurate than the standard MODIS snow cover product delivered by NSIDC DAAC

# The MODIS Spectrum





# MODSCAG



$$R_{S,\lambda} = \sum_{i=1}^N F_i R_{\lambda,i} + \varepsilon_{\lambda}$$

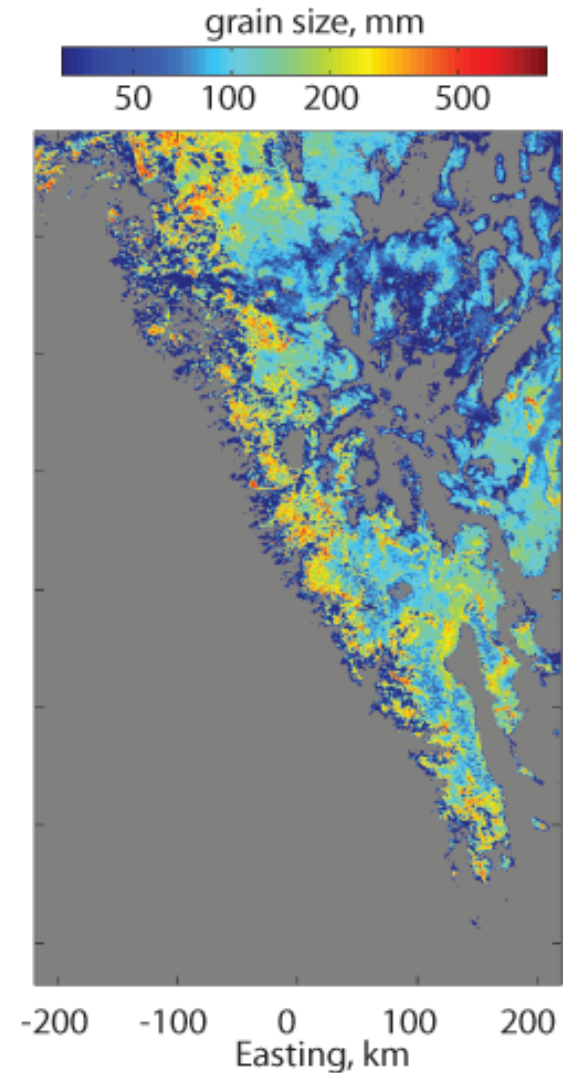
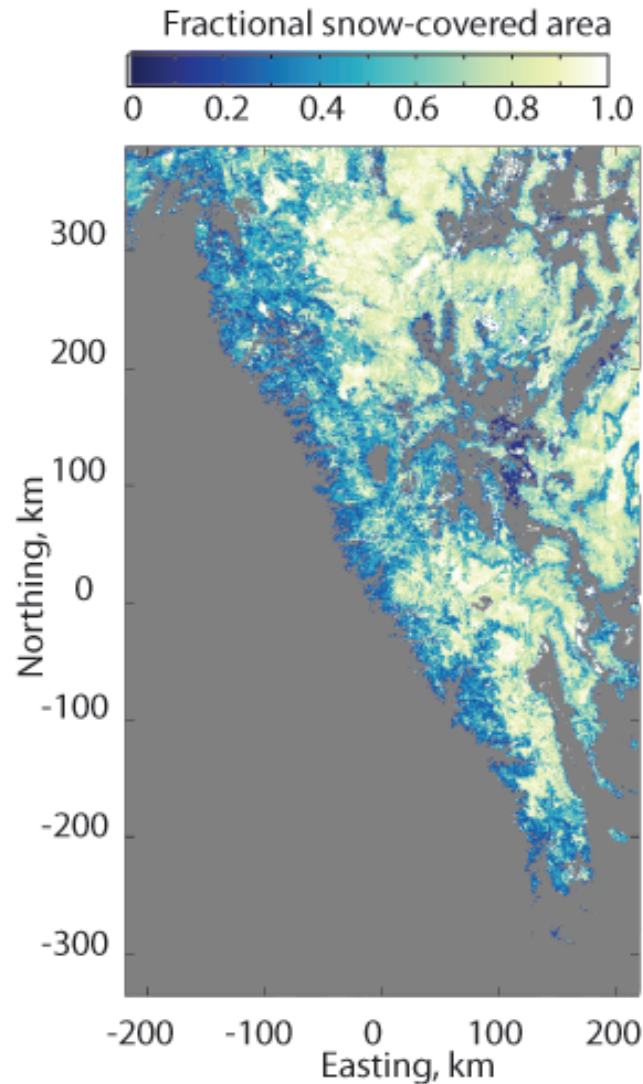
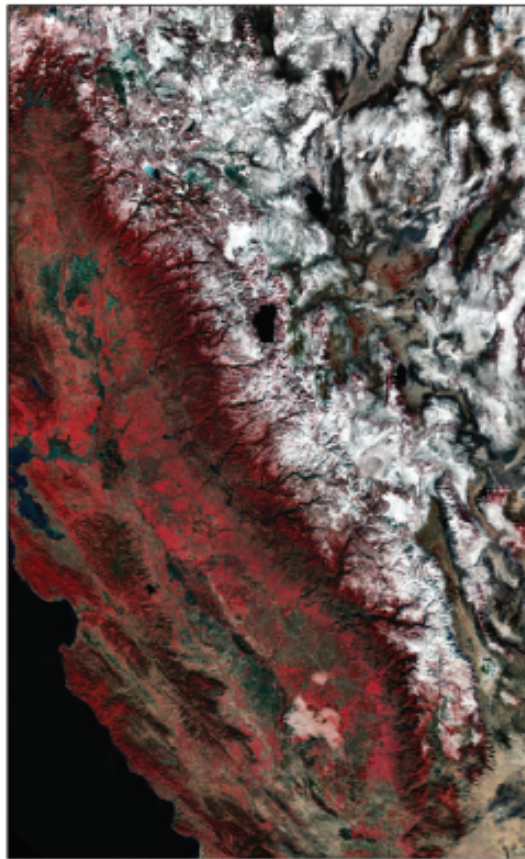
$$\text{RMSE} = \left( \frac{1}{M} \sum_{\lambda=1}^M \varepsilon_{\lambda}^2 \right)^{1/2}$$

$$f_{\text{SCA}} = \frac{F_S}{\sum_{p \in s,v,r} F_p} = \frac{F_S}{1 - F_{\text{shade}}}$$

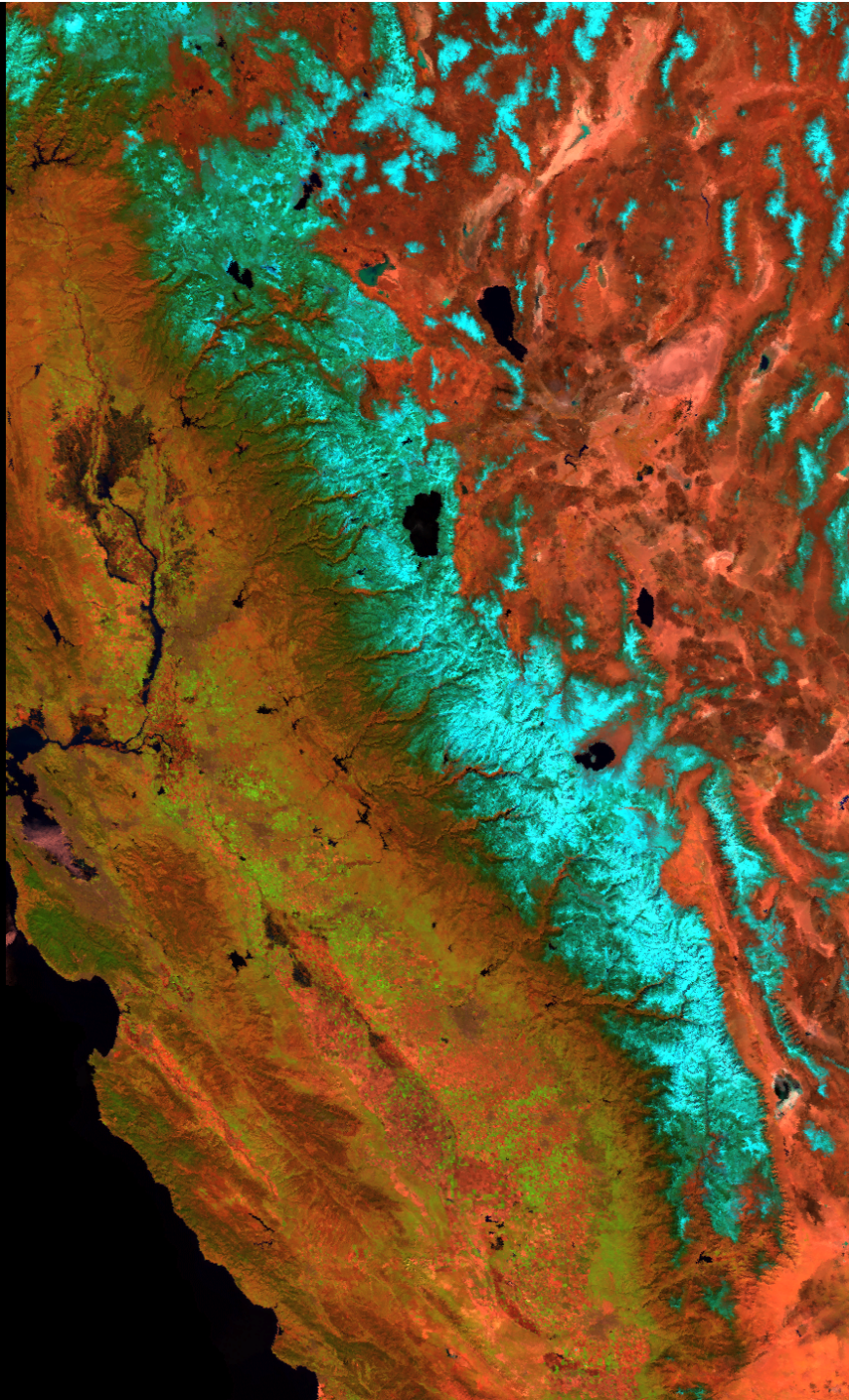
*Painter et al, 2009*

# MODSCAG Products

Bands 2,4,3 (RGB)










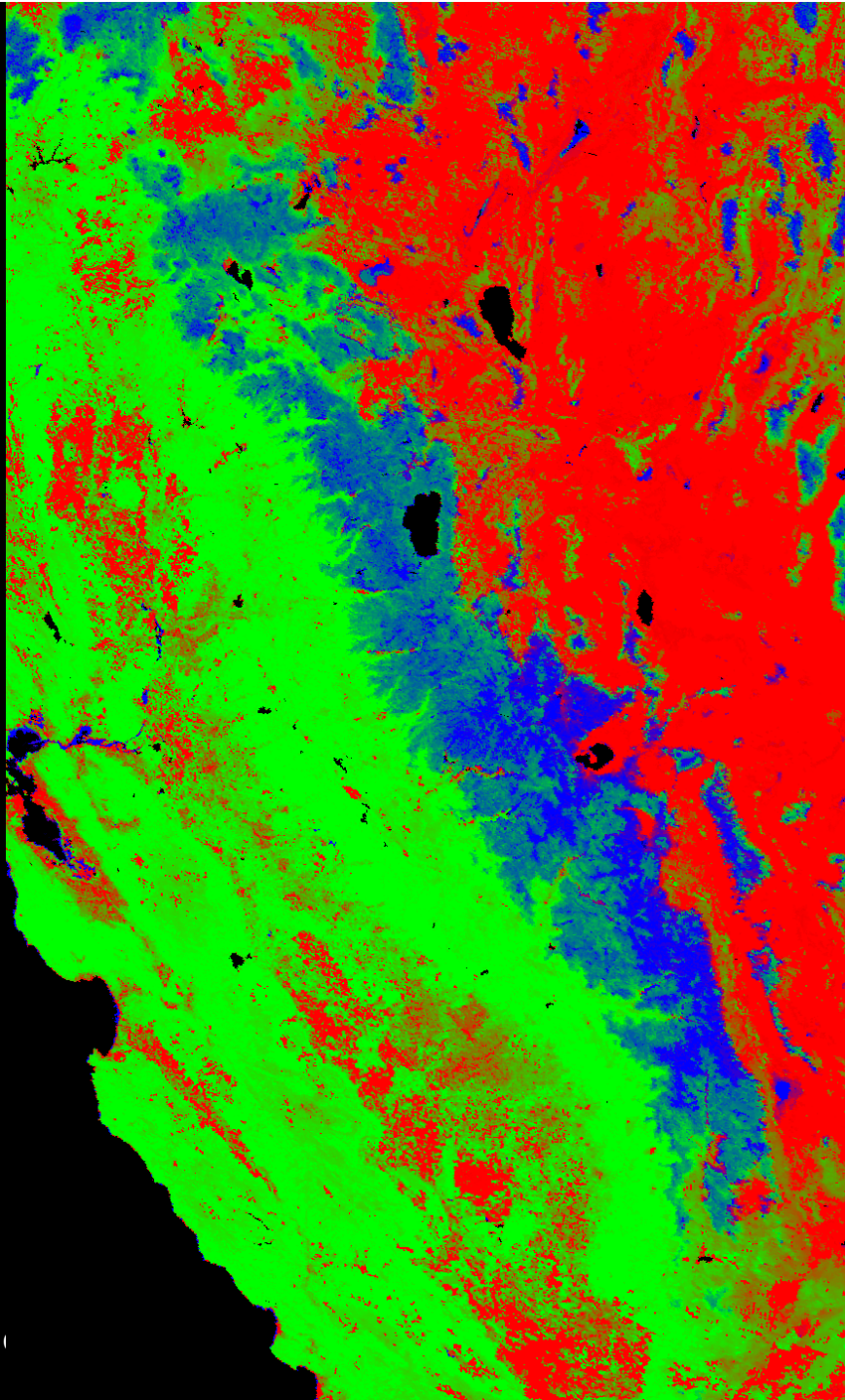
MODIS Color Composite  
*Sierra Nevada*  
*April 1, 2005*



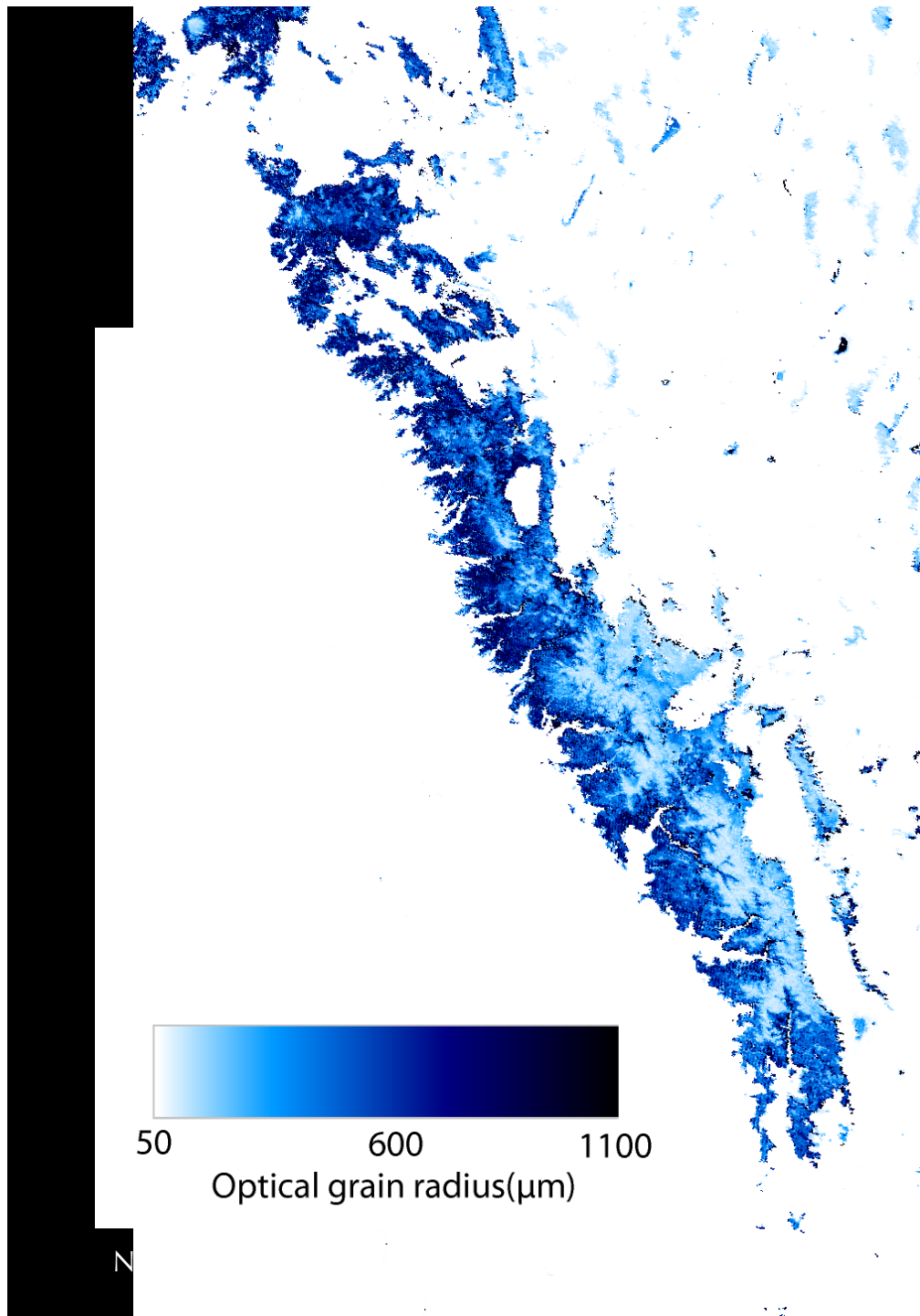
MODSCAG retrievals  
*Sierra Nevada*  
*April 1, 2005*

-  100% Snow Cover
-  100% Vegetation Cover
-  100% Rock Cover

N



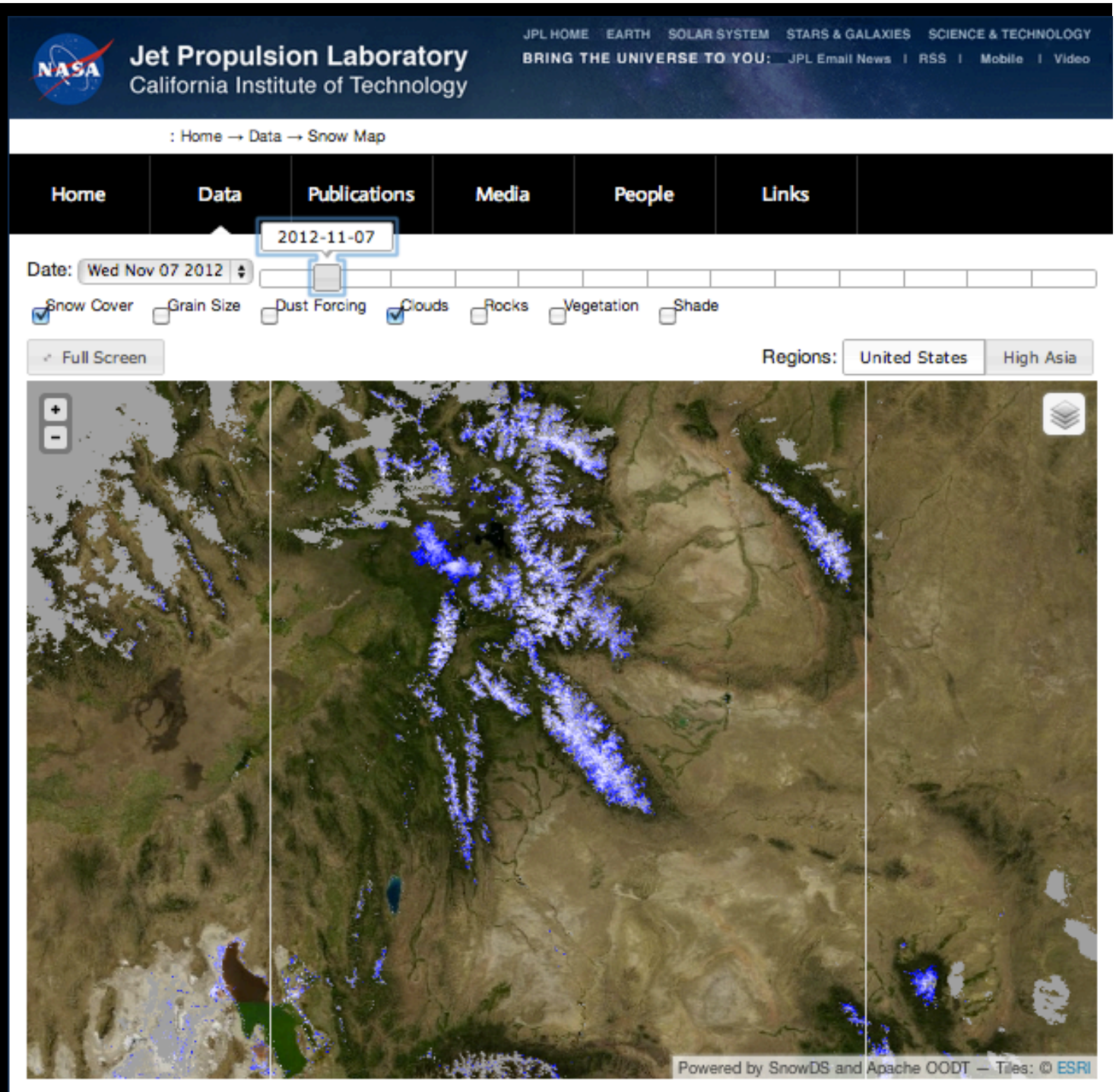




MODSCAG retrievals  
*Sierra Nevada*  
*April 1, 2005*

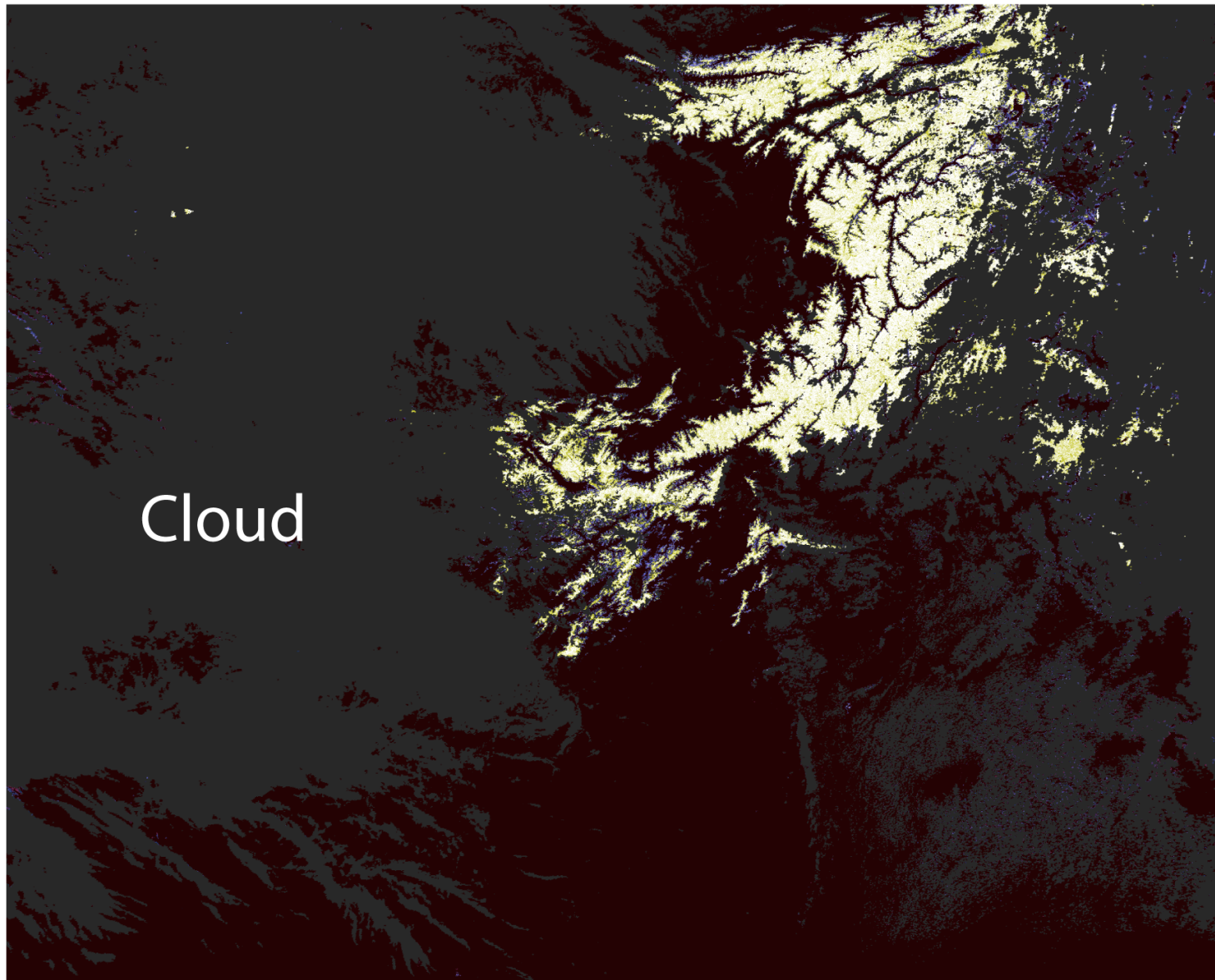
*Snow Grain Size*

# JPL Snow Data Server





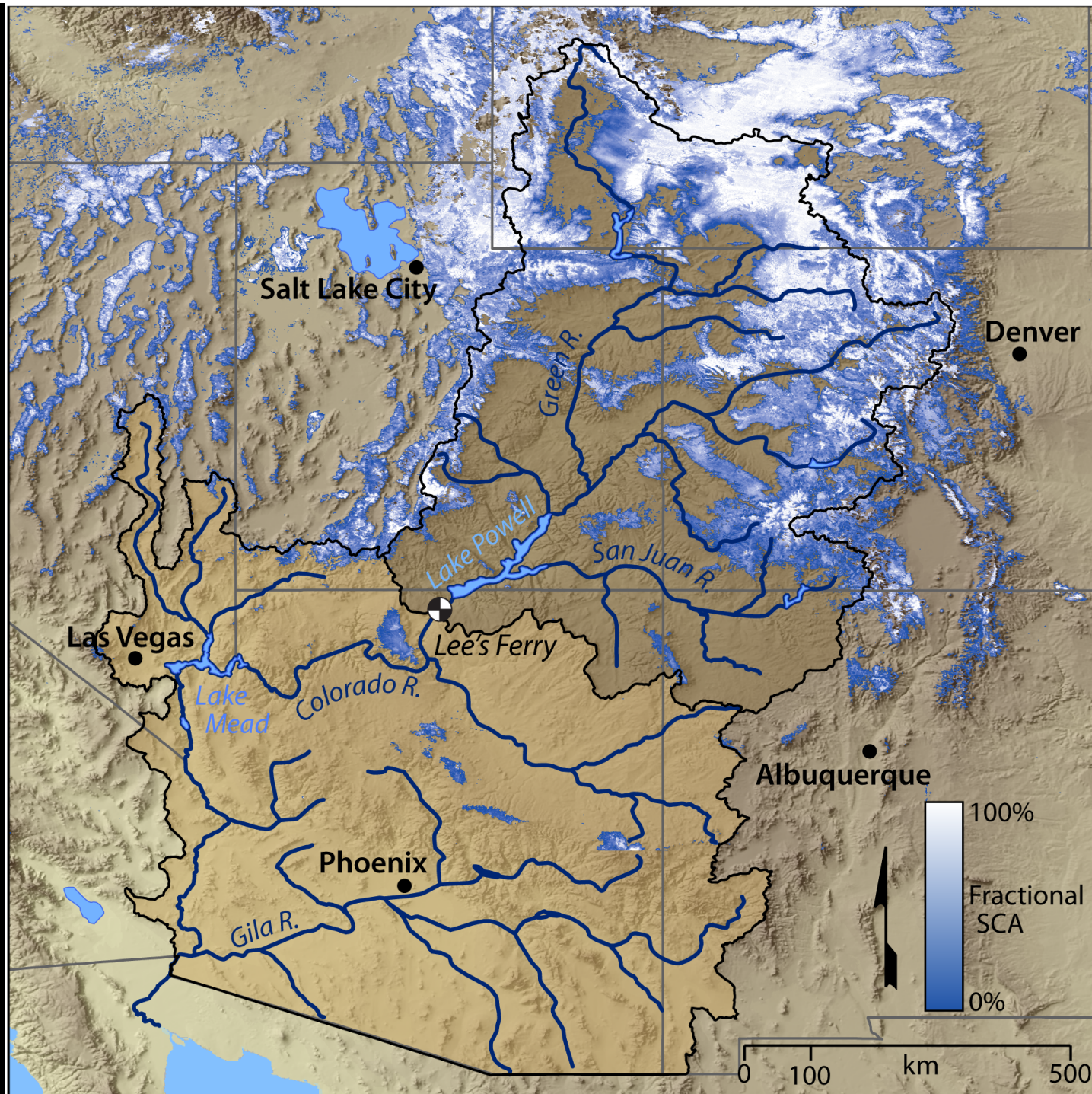
# Hindu Kush April 9/2009



Fractional Snow Cover



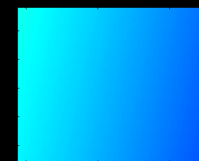
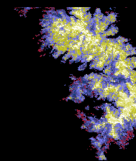
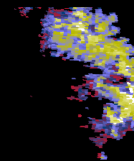
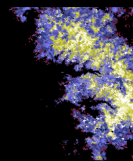
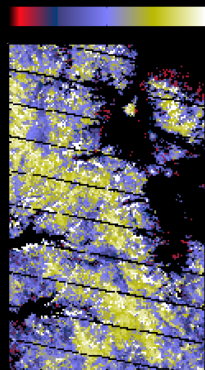
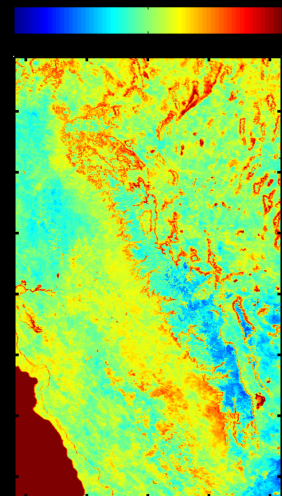






# MODSCAG Constraints

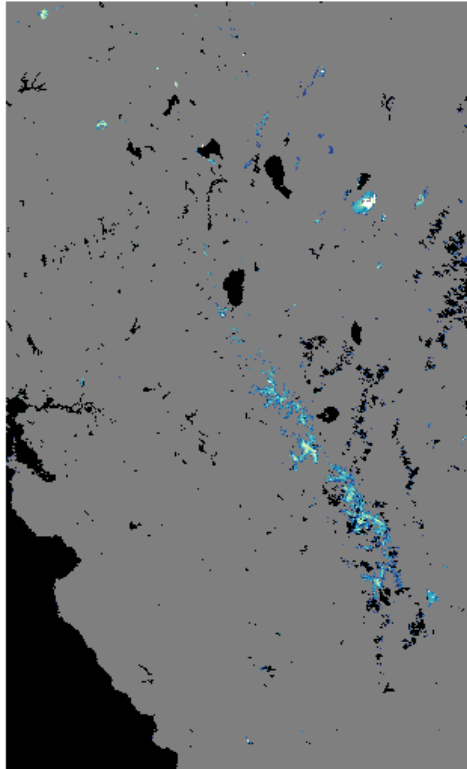
- No mapping under cloud cover
- Detection limits: 15-100% fSCA
- Geometric considerations
- Noise considerations



# Comparison with other products

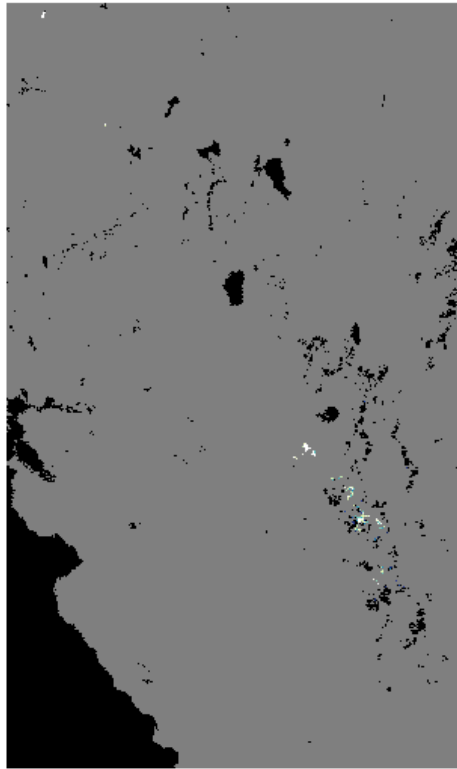
MODSCAG

MODSCAG, July 10, 2006



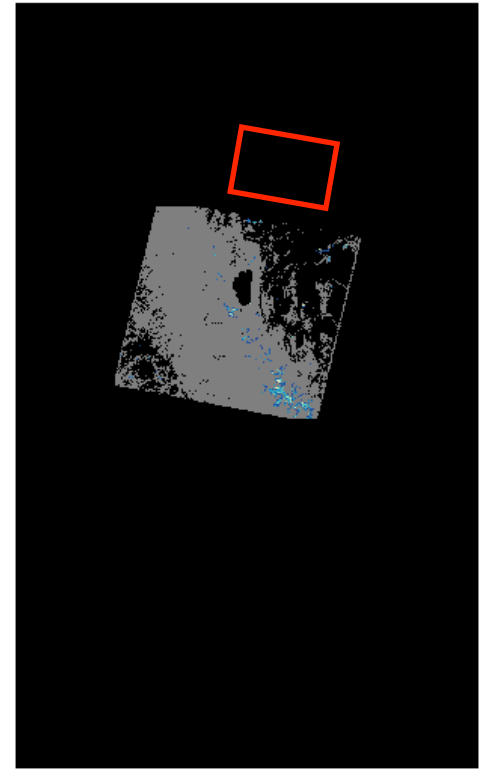
Standard MODIS  
Snow Product

MOD10A1, July 10, 2006



High resolution  
Thematic Mapper

TMSCAG, July 11, 2006





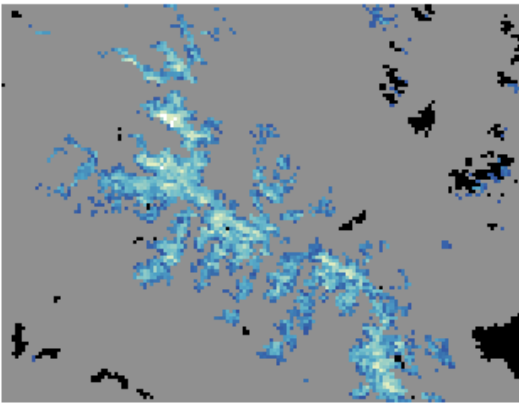
# Comparison with older products

MODSCAG

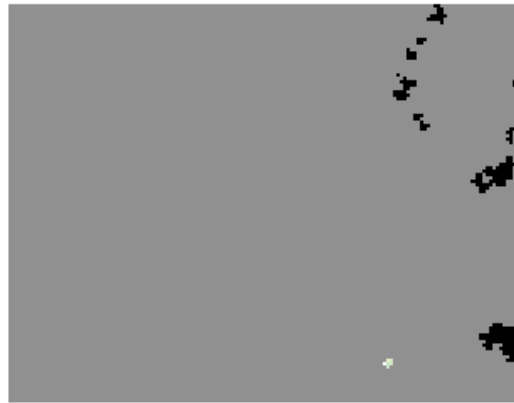
Standard MODIS  
Snow Product

High resolution  
Thematic Mapper

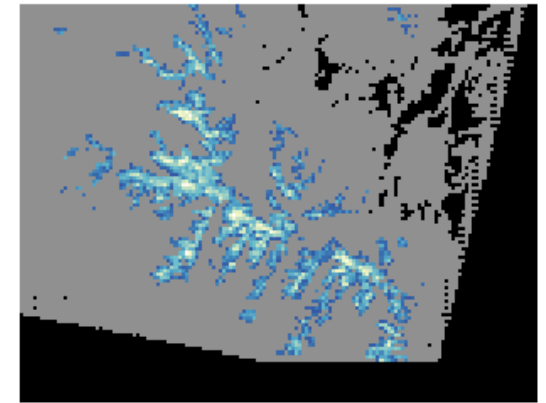
MODSCAG, July 10, 2006



MOD10A1, July 10, 2006



TMSCAG, July 11, 2006



MODSCAG sees snow missed by other products and also provides better spatial coverage than some other products

Rittger et al (2012)

# **MODSCAG-DERIVED PRODUCTS**

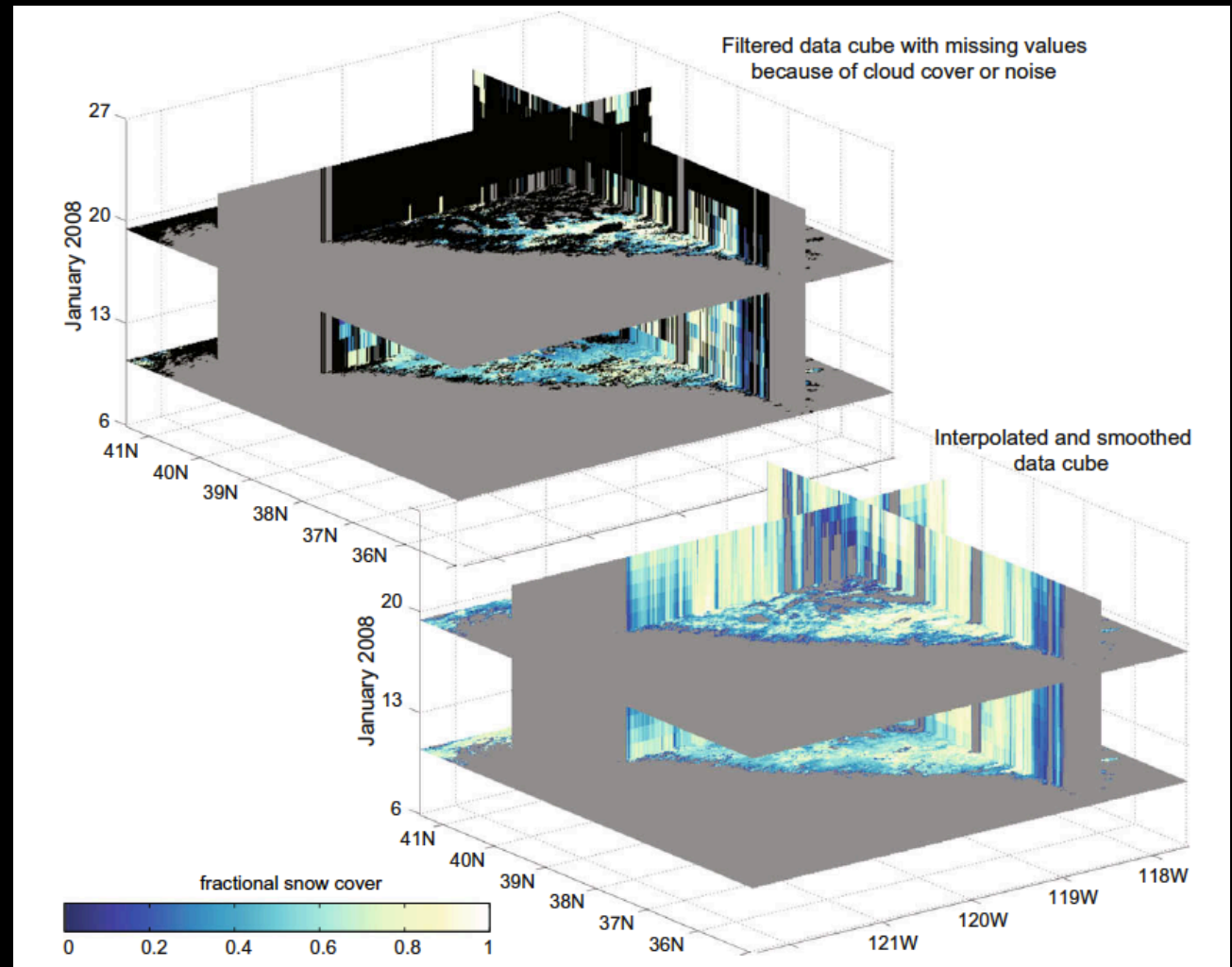


# Time-Space Continuity

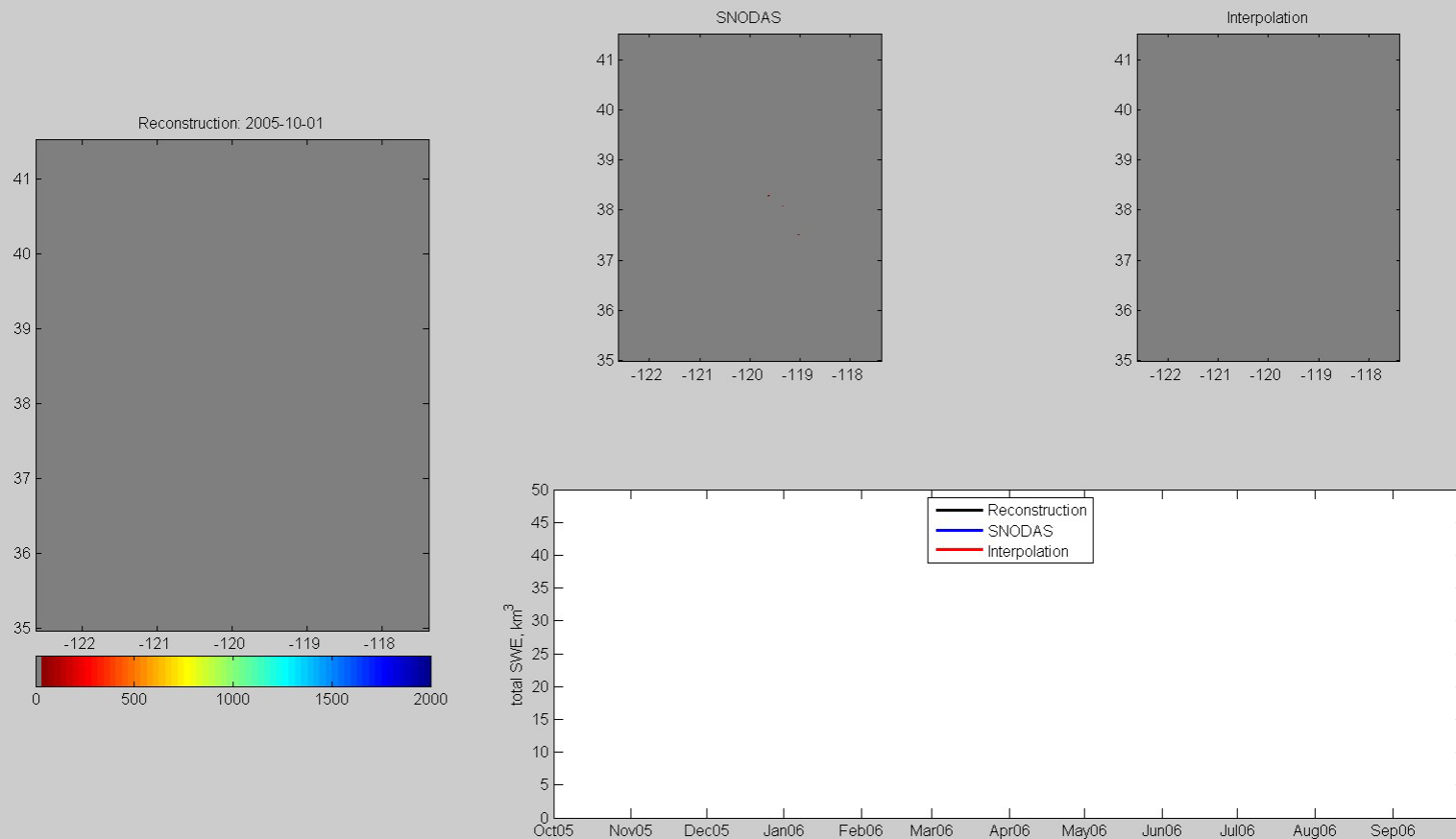
Time-space filtering of instantaneous MODSCAG retrievals to spatially and temporally continuous fields of fractional snow covered area and albedo.

Constrained by cloud cover, sensor geometry

*Dozier et al (2008)*



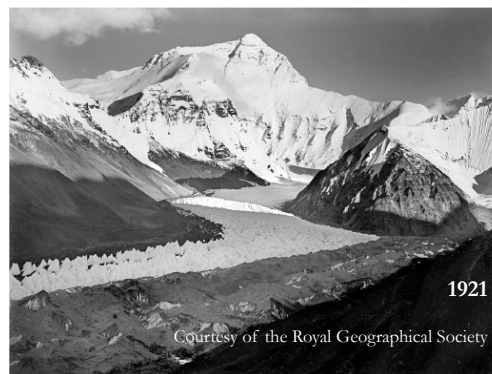
# Snow Water Equivalent





# Fate of Mountain Glaciers in the Anthropocene

*A Report by the Working Group Commissioned by the Pontifical Academy of Sciences*



Main Rongbuk Glacier (see inside page)

May 11, 2011



*The working group consists of glaciologists, climate scientists, meteorologists, hydrologists, physicists, chemists, mountaineers, and lawyers organized by the Pontifical Academy of Sciences at the Vatican, to contemplate the observed retreat of the mountain glaciers, its causes*

# GLIMS

*The Global Land Ice Measurements from Space (GLIMS) project has compiled digital glacier outlines and related metadata for the majority of the world's glaciers but **inconsistency among product algorithms and time periods represented precludes the production of a consistently derived global dataset.***

*Moreover, these products have single points in time and themselves have uncertainties because of lack of knowledge about subsequent snowmelt in that season. Therefore, trend analysis is impossible from the vast majority of these products.*



# Need for MODICE product

Currently a fundamental missing component of the world cryosphere inventory is a single systematically derived base map of the world's glaciers and annual minimum snow cover, at any scale. Moreover, we need a product that offers annual resolution to facilitate knowledge of trends.

# MODIS Permanent Ice (MODICE)

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, LXXXXX, doi:10.1029/2012GL053340, 2012

## **<sup>1</sup> Automated mapping of Earth's annual minimum exposed snow <sup>2</sup> and ice with MODIS**

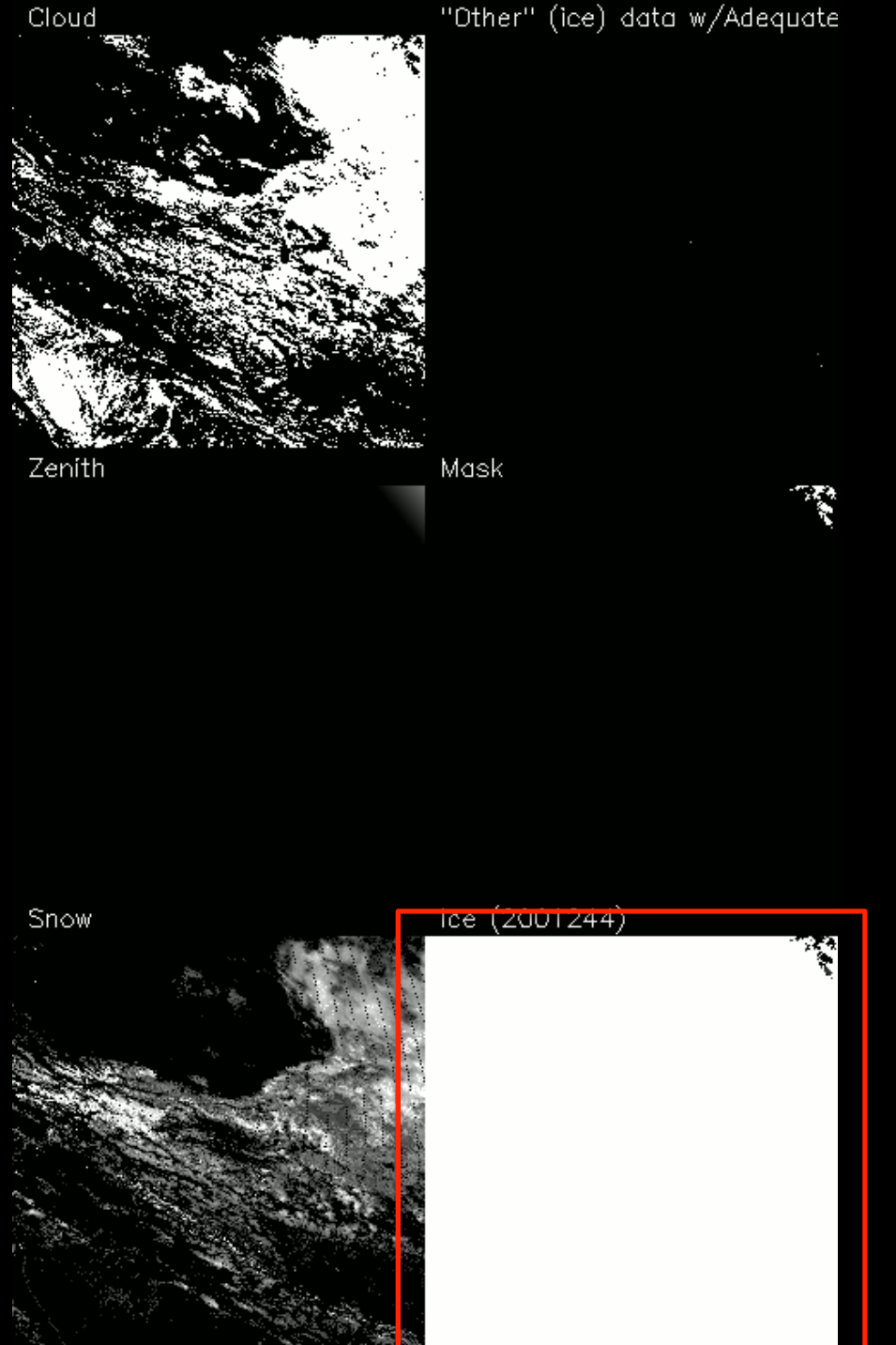
**<sup>3</sup> Thomas H. Painter,<sup>1</sup> Mary J. Brodzik,<sup>2</sup> Adina Racoviteanu,<sup>3</sup> and Richard Armstrong<sup>2</sup>**

**<sup>4</sup> Received 31 July 2012; revised 12 September 2012; accepted 19 September 2012; published XX Month 2012.**



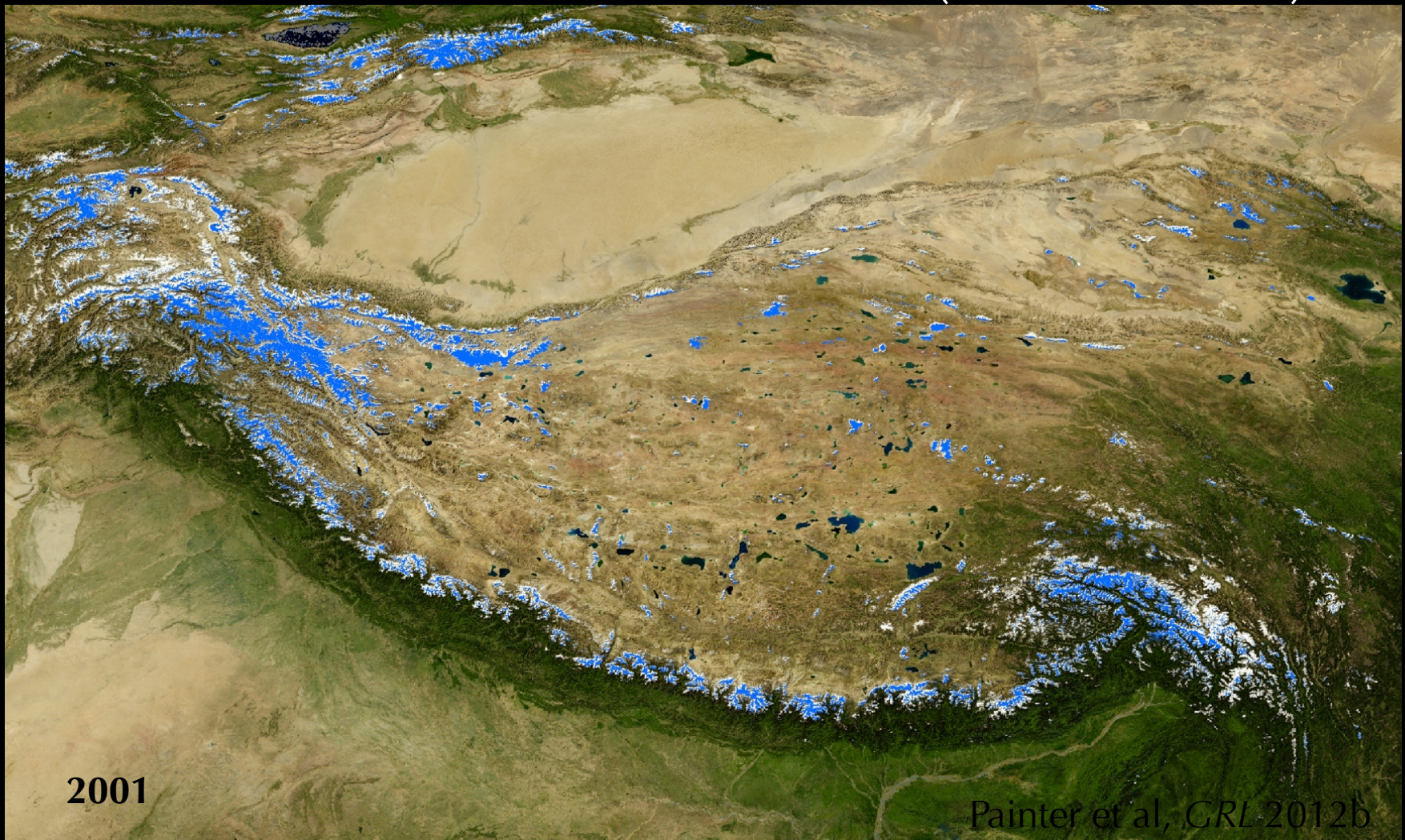
# MODSCAG feeds MODICE

We start with 100% ice everywhere in each year. Then use the daily MODSCAG snow/ice retrievals (subject to clear skies and good viewing geometry) to determine where no snow appears. Thereafter that pixel is removed from annual minimum snow and ice cover.





# MODIS Permanent Ice (MODICE)





# Summary

- Snowmelt is dominant water source in Western US and other regions of the globe
- Absorbed sunlight controls snowmelt
- Accurate mapping of snow cover necessary for climate science and water management
- MODSCAG is most accurate snow product available
- Time-space smoothed products available
- MODSCAG used for SWE reconstruction
- MODSCAG used for global glacier modeling

# Next week

- Impacts of dust and black carbon on snowmelt
- Impacts on runoff and glacier mass balance
- Impact of dust/BC on snow reflectance
- Mapping of dust/BC radiative forcing in snow from MODIS
- MODDRFS product
- Sensitivity of runoff forecasting to dust radiative forcing